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NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

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Written for Van Nostrand's Magazine.

I.

It is the object of the series of articles, of which this is the first, to fully discuss the stability of all forms of the arch, flexible or rigid, by means of the equilibrium polygon—the now well recognized instrument for graphical investigation. One or two other constructions of interest may also be added in the sequel. The discussion will pre-suppose an elementary knowledge of the properties of the equilibrium polygon, and its accompanying force polygon, for parallel forces.

As ordinarily used in the discussion of the simple or continuous girder, the equilibrium polygon has an entirely artificial relation to the problem in hand, and the particular horizontal stress assumed is a matter of no consequence; but not so with respect to the arch. As will be seen, there is a special equilibrium polygon appertaining to a given arch and load, and in this particular polygon the horizontal stress is the actual horizontal thrust of the arch. When this thrust has been found in any given case, it permits an immmediate determination of all other questions respecting the stresses. This thrust has to be determined differently in arches of different kinds, the method being dependent upon the number, kind, and position of the joints in the arch.

The methods we shall use depend upon our ability to separate the stresses induced by the loading into two parts; one part being sustained in virtue of the reaction of the arch in the same manner as an inverted suspension cable (*i.e.*, as an equilibrated linear arch), and the remainder in virtue of its reaction as a girder. These two ways in which the loading is sustained are to be considered somewhat apart from each other. To this end it appears necessary to restate and discuss, in certain aspects, the well-known equations applicable to elastic girders acted on by vertical pressures due to the load and the resistances of the supports.

Let P represent any one of the various pressures, P_1, P_2, P_n, applied to the girder.

Consider an ideal cross section of the girder at any point O.

Let x=the horizontal distance from O to the force P.

Let R=the radius of curvature of the girder at O.

At the cross section O, the equations just mentioned become

Shearing stress, $S = \Sigma\ (P)$

Moment of flexure, $M = \Sigma\ (Px)$

Curvature, $P' = \frac{1}{R} = \frac{M}{EI}$

Total bending, $B = \Sigma(P') = \Sigma\left(\frac{M}{EI}\right)$

Deflection, $D = \Sigma\ (P'x) = \Sigma\left(\frac{Mx}{EI}\right)$

in which E is the modulus of elasticity of the material, and I is the moment of inertia of the girder, and as is well known, the summation is to be extended from the point O to a free end of the girder, or, if not to a free end, the summation expresses the effect only of the quantities included in the summation.

Let a number of points be taken at equal distances along the girder, and let the values of P, S, M, B, D be computed for these points by taking O at these points successively, and also erect ordinates at these points whose lengths are proportional to the quantities computed. First, suppose I is the same at each of the points chosen, then the values of these ordinates may be expressed as follows, if a, b, c, etc., are any real constants whatever:

$$y_p = a \,.\, P \quad . \quad . \quad . \quad (1)$$
$$y_s = b \,.\, \Sigma(P) \quad . \quad . \quad (2)$$
$$y_m = c \,.\, \Sigma(Px) = c \,.\, M \,. \,. \quad (3)$$
$$y_b = d \,.\, \Sigma(M) \quad . \quad . \quad (4)$$
$$y_d = \varepsilon \,.\, \Sigma(Mx) \quad . \quad . \quad (5)$$

If I is not the same at the different cross sections, then the last three equations must be replaced by the following:

$$y_m' = f \,.\, P' \quad . \quad . \quad (3')$$
$$y_b' = g \,.\, \Sigma(P') \quad . \quad . \quad (4')$$
$$y_d' = h \,.\, \Sigma(P'x) \,. \quad . \quad (5')$$

The ordinates y_m and y_m' are not equal, but can be obtained one from the other when we know the ratio of the moments of inertia at the different cross sections.

Equation (1) expresses the loading, and y_p may be considered to be the depth of some uniform material as earth, shot or masonry constituting the load. Lines joining the extremities of these ordinates will form a polygon, or approximately a curve which is the upper surface of such a load. When the load is uniform the surface is a horizontal line.

For the purposes of our investigation, a distributed load whose upper surface is the polygon or curve, above described, is considered to have the same effect as a series of concentrated loads proportional to the ordinates y_p acting at the assumed points of division. If the points of division be assumed sufficiently near to each other, the assumption is sufficiently accurate.

If a polygon be drawn in a similar manner by joining the extremities of the ordinates y_m computed from equation (3), it is known that this polygon is an equilibrium polygon for the applied weights P, and it can also be constructed directly without computation by the help of a force polygon having some assumed horizontal stress.

Now, it is seen by inspection that equations (3) and (5), or (3′) and (5′), have the same relationship to each other that equations (1) and (3) have. The relationship may be stated thus:—If the ordinates y_m (or y_m') be regarded as the depth of some species of loading, so that the polygonal part of the equilibrium polygon is the surface of such load, then a second equilibrium polygon constructed for this loading will have for its ordinates y_d. But these last are proportional to the actual deflections of the girder.

Hence a second equilibrium polygon, so constructed, might be called the deflection polygon, as it shows on an exaggerated scale the shape of the neutral axis of the deflected girder.

The first equilibrium polygon having the ordinates y_m may be called the moment polygon.

It may be useful to consider the physical significance of equations (3), (4), (5), or (3′), (4′), (5′).

According to the accepted theory of perfectly elastic material, the sharpness of the curvature of a uniform girder is directly proportional to the moment of the applied forces, and for different girders or different portions of the same girder, it is inversely proportional to the resistance which the girder can afford. Now this resistance varies directly as I varies, hence curvature varies as $M \div I$, which is equation (3) or (3′).

Now curvature, or bending at a point, is expressed by the acute angle between two tangents to the curve at the distance of a unit from each other; and the total bending, *i.e.* the angle between the tangent at O, and that at some distant point A is the sum of all such angles between O and the point A. Hence the total bending is proportional to $\Sigma(M \div I)$, the summation being extended from O to the point A, which is equation (4) or (4′).

Again, if bending occurs at a point distant from O as A, and the tangent at A be considered as fixed, then O is deflected from this tangent, and the amount of such deflection depends both upon the amount of the bending at A, and upon its distance from O. Hence the deflection from the tangent at A is proportional to $\Sigma(Mx \div I)$ which is equation (5) or (5′).

It will be useful to state explicitly several propositions, some of which are implied in the foregoing equations. The importance and applicability of some of them has not, perhaps, been sufficiently recognized in this connection.

Prop. I. Any girder (straight or otherwise) to which vertical forces alone are applied (*i. e.*, there is no horizontal thrust) sustains at any cross-section the stress due to the load, solely by developing one internal resistance equal and opposed to the shearing, and another equal and opposed to the moment of the applied forces.

Prop. II. But any flexible cable or arch with hinge joints can offer no resistance at these joints to the moment of the applied forces, and their moment is sustained by the horizontal thrust developed at the supports and by the tension or compression directly along the cable or arch.

It is well known that the equilibrium polygon receives its name from its being the shape which such a flexible cable, or equilibrated arch, assumes under the action of the forces. In this case we may say for brevity, that the forces are sustained by the cable or arch in virtue of its being an equilibrium polygon.

Prop. III. If an arch not entirely flexible is supported by abutments against which it can exert a thrust having a horizontal component, then the moment due to the forces applied to the arch will be sustained at those points which are not flexible, partly in virtue of its being approximately an equilibrium polygon, and partly in virtue of its resistance as a girder.

It is evident from the nature of the equilibrium polygon that it is possible with any given system of loading to make an arch of such form (viz., that of an equilibrium polygon) as to require no bracing whatever, since in that case there will be no tendency to bend at any point. Also it is evident that any deviation of part of the arch from this equilibrium polygon would need to be braced. As, for example, in case two distant points be joined by a straight girder, it must be braced to take the place of part of the arch. Furthermore, the greater the deviation the greater the bending moment to be sustained in this manner. Hence appears the general truth stated in the proposition.

It will be noticed that the moment called into action, at any point of a straight girder, depends not only on the applied forces which furnish the polygonal part of the equilibrium polygon, but also on the resistance which the girder is capable of sustaining at joints or supports, or the like. For example, if the girder rests freely on its end-supports, the moment of resistance vanishes at the ends, and the "closing line" of the polygon joins the extremities of the polygonal part. If however the ends are fixed horizontally and there are two free (hinge) joints at other points of the girder, the polygonal part will be as before, but the closing line would be drawn so that the moments at those two points vanish. Similarly in every case (though the conditions may be more complicated than in the examples used for illustration) the position of the closing line is fixed by the joints or manner of support of the girders, for these furnish the conditions which the moments (*i. e.*, the ordinates of the equilibrium polygon) must fulfill. For example, in a straight uniform girder without joints and fixed horizontally at the ends, the conditions are evidently these; the total bending vanishes when taken from end to end, and the deflection of one end below the tangent at the other end also vanishes.

Prop. IV. If in any arch that equilibrium polygon (due to the weights) be constructed which has the same horizontal thrust as the arch actually exerts; and if its closing line be drawn from consideration of the conditions imposed by the supports, etc.; and if furthermore the curve of the arch itself be regarded as another equilibrium polygon due to some system of loading not given, and its closing line be also found from the same considerations respecting supports, etc., then, when these two polygons are placed so that these closing lines coincide and their areas partially cover each other, the ordinates intercepted between these two polygons are proportional to the real bending moments acting in the arch.

Suppose that an equilibrium polygon due to the weights be drawn having the same horizontal thrust as the arch. We are in fact unable to do this at the outset as the horizontal thrust is unknown. We only suppose it drawn for the purpose of discussing its properties. Let also the closing line be drawn, which may be done, as will be seen hereafter. Call the area between the closing line and the polygon, A. Draw the closing line of the curve of the arch itself (regarded as an equilibrium polygon) according to the same law, and call the area between this closing line and its curve A''. Further let A' be the area of a polygon whose ordinates represent the actual moments bending the arch, and drawn on the same scale as A and A''. Since the supports etc., must influence the position of the closing line of this polygon in the same manner as that of A, we have by Prop. III not only

$$A = A' + A''$$

which also applies to the entire areas, but also

$$y = y' + y''$$

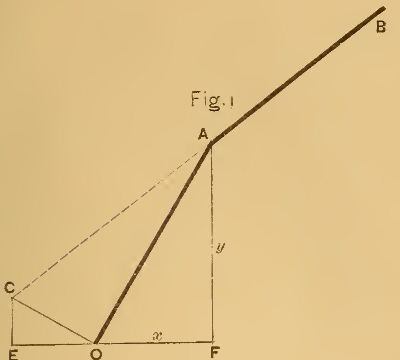
as the relation between the ordinates of these polygons at any of the points of division before mentioned, from which the truth of the proposition appears.

This demonstration in its general form may seem obscure since the conditions imposed by the supports, etc., are quite various, and so cannot be considered in a general demonstration. The obscurity, however, will disappear after the treatment of some particular cases, where we shall take pains to render the truth of the proposition evident. We may, however, make a statement which will possibly put the matter in a clearer light by saying that A'' is a figure easily found, and we, therefore, employ it to assist in the determination of A' which is unknown, and of A which is partially unknown. And we arrive at the peculiar property of A'', that its closing line is found in the same manner as that of A, by noticing that the positions of the closing lines of A and A' are both determined in the same manner by the supports, etc.; for the same law would hold when the rise of the arch is nothing as when it has any other value. But A'' is the difference of A and A'. Hence what is true of A and A' separately is true of their difference A'', the law spoken of being a mere matter of summation.

From this proposition it is also seen that the curve of the arch itself may be regarded as the curved closing line of the polygon whose ordinates are the actual bending moments, and the polygon itself is the polygonal part of the equilibrium polygon due to the weights.

It is believed that Prop. IV contains an important addition to our previous knowledge as to the bending moments in an arch, and that it supplies the basis for the heretofore missing method of obtaining graphically the true equilibrium polygon for the various kinds of arches.

Prop. V. If bending moments M act on a uniform inclined girder at horizontal distances x from O, the amount of the vertical deflection y_d will be the same as that of a horizontal girder of the same cross section, and having the same horizontal span, upon which the same moments M act at the same horizontal distances x from O. Also, if bending moments M act as before, the amount of the horizontal deflection, say x_d, will be the same as that of a vertical girder of the same cross section, and having the same height, upon which the same moments M act at the same heights.



Let the moment M act at A, producing according to equation (5) the deflection

$$OC=e.M.AO$$

whose horizontal and vertical components are

$$y_d = CE \quad \text{and} \quad x_d = OE$$

For the small deflections occurring in a girder or arch, $AOC=90°$

$$\therefore AO : OF :: OC : CE$$

$$\therefore CE=\frac{OC}{AO}.OF=e.M.OF$$

$$\therefore y_d = e.Mx$$

Also, $AO : AF :: OC : OE$

$$\therefore OE=\frac{OC}{AO}.AF=e.M.AF$$

$$\therefore x_d = e.My$$

The same may be proved of any other moments at other points; hence a similar result is true of their sum; which proves the proposition.

It may be thought that the demonstration is deficient in rigor by reason of the assumption that $AOC=90°$.

Such, however, is not the fact as appears from the analytic investigation of this question by Wm. Bell in his attempted graphical discussion of the arch in Vol. VIII of this Magazine, in which the only approximation employed is that admitted by all authors in assuming that the curvature is exactly proportional to the bending moment.

We might in this proposition substitute $f.M \div I$ for $e.M$, and prove a similar but more general proposition respecting deflections, which the reader can easily enunciate for himself.

Before entering upon the particular discussions and constructions we have in view, a word or two on the general question as to the manner in which the problem of the arch presents itself, will perhaps render apparent the relations between this and certain previous investigations. The problem proposed by Rankine, Yvon-Villarceaux, and other analytic investigators of the arch, has been this :—Given the vertical loading of an arch, what must be its form, and what must be the resistances of the spandrils and abutments, when the weights produce no bending moments whatever? By the solution of this question they obtain the equation and properties of the particular equilibrium polygon which would sustain the given weights. Our graphical process completely solves this question by at once constructing this equilibrium polygon. It may be remarked in this connection, that the analytic process is of too complicated a nature to be effected in any, except a few, of the more simple cases, while the graphical process treats all cases with equal ease. But the kind of solution just noticed, is a very incomplete solution of the problem presented in actual practice; for, any moving load disturbs the distribution of load for which the arch is the equilibrium polygon, and introduces bending moments. The arch must then be proportioned to resist these moments.

For similar reasons it is not necessary to stiffen a suspension bridge. Since this is the case, it is of no particular consequence that the form adopted for the arch in any given case, should be such as to entirely avoid bending moments when not under the action of the moving load. So far as is known to us, it is the universal practice of engineers to assume the form and dimensions, as well as the loading of any arch projected, and next to determine whether the assumed dimensions are consistent with the needful strength and stability. If the assumption is unsuited to the case in hand, the fact will appear by the introduction of excessive bending moments at certain points. The considerations set forth furnish a guide to a new assumption which shall be more suitable, it being necessary to make the form of the arch conform more closely to that of the equilibrium polygon for the given loading.

The question may be regarded as one

of economy of material, and ease of construction, analogous to that of the truss bridge. In this latter case, constructors have long since abandoned any idea of making bridges in which the inclination of the ties and posts should be such as to require theoretically the minimum amount of material. Indeed, the amount of material in the case of a theoretic minimum, differs by such an inconsiderable quantity from that in cases in which the ties and posts have a very different inclination, that the attainment of the minimum is of no practical consequence.

Similar considerations applied to the arch, lead us to the conclusion that the form adopted can in every case be formed of segments of one or more circles, and that for the purpose of construction every requirement will then be met as fully as by the more complicated transcendental curves found by the writers previously mentioned. If considerations of an artistic nature render it desirable to adopt segments of parabolas, ellipses or other ovals, it will be a matter of no more consequence than is the particular style of truss adopted by rival bridge builders.

We can also readily treat the problem in an inverse manner, viz:—find the system of loading, of which the assumed curve of the arch is the equilibrium polygon. From this it will be known how to load a given arch so that there shall be no bending moments in it. This, as may be seen, is often a very useful item of information; for, by leaving open spaces in the masonry of the spandrils, or by properly loading the crown to a small extent, we may frequently render a desirable form entirely stable and practicable.

FIRE-BRICKS.*

By Mr. J. DUNNACHIE.

From "Iron."

The fire-brick question may be viewed from various sides. The owner of furnaces who uses the bricks, the man of science who has to do with their chemistry and other technicalities, and the brickmakers who manufacture them, should all have something to say on the subject. In the present paper, we will view it from the brickmaker's standpoint, and will strictly confine ourselves to that branch of the fire-clay trade indicated by the title.

The iron and steel manufacturer, who may be taken as the representative of furnace owners, has in various ways recently shown a deep interest in this subject. In the iron trade journals of this and other countries, it bulks up as one of the pressing questions, and at the last three meetings of the Iron and Steel Institute, it has been under discussion, in connection with a paper read by Mr. Snelus, of the West Cumberland Iron and Steel Company, which will be found published in the reports of the Institute for 1875 and 1876. These discussions are valuable, being the latest utterances of some of our first scientific and practical men.

The metal smelter observes that his furnaces, unlike his other buildings, are continually melting and crumbling away. He is steadily increasing the magnitude of his operations, and the intensity of his heats, and finds his progress arrested by the weakness of his furnace materials. The tear and wear has increased, until it has become a serious item in the cost of production, and for this he naturally seeks a remedy. This is pre-eminently a chemical question, not for analysis merely, but that every peculiarity of form, proportion, relationship, and general conditions may be carefully and accurately observed, and data established, which will give us something to aim at and something to guide us in our everyday practice as manufacturers. Much has been done already, and there are indications of an increasing chemical interest in the subject, which, with the co-

* A paper read at the British Association, Glasgow.

operation of the consumers and manufacturers of fire-bricks, may ultimately lead to results that will meet all the wants of practical metallurgy.

Silica, alumina, bauxite, carbon, magnesia, lime, are all highly refractory, the two first-named, silica and alumina, being the essential constituents of our fire-clays. Lime and magnesia, though practically indestructible by heat, fuse easily when combined with silica, and are consequently classed with oxide of iron, potash, soda, &c., amongst the impurities of fire-clay. Experiments are at present in progress with several of the ingredients named, and important results are expected in more directions than one.

The great variety of purposes for which fire-bricks are used, and the various, and even opposite qualities required in them, make it impossible that one brick can answer for all descriptions of furnaces. They require to stand strong heat, change of temperature, in some cases heavy pressure, and hard knocks, and also fluxing and chemical action of various kinds. For all these purposes we require not one, but a variety of bricks, and this variety we will probably find sooner or later in the different refractory substances at our disposal.

The age of a fire-brick depends upon the purpose for which it is used. In some situations it may be counted by minutes, in others by years; and some bricks will last for years in positions where others also bearing the name of fire-bricks would be destroyed in as many weeks.

The name fire-clay covers a multitude of qualities, and fire-bricks differ to such an extent chemically, and as manufactured articles, that if their names were to indicate their qualities, rather than the general purpose to which they are put, a great many new names would require to be invented or imported. Although no one brick answers for all purposes, a great deal can be done in the process of manufacture to fit it for the particular use to which it is to be put; one requires to be solid and close-bodied, another porous and open; in certain special cases soft burning is preferred, while in others they cannot be too hard. As a general rule, fire-bricks should be hard burned. The shrink from the green state to the burned condition is generally about one-twelfth of the bulk, and if this is not entirely reduced in the kiln, some of it will require to be burned out of them after they are built in the furnace, and this must injure the stability of the furnace.

Mixing clays of different kinds has been recommended, with the view of combining the good qualities of each, and more especially to increase or diminish the relative proportion of silica. This may do good in some cases, but as all fire-clays have their bad qualities also, mixing will, in many cases, increase the force of these, and so do more harm than good. Riley says, touching this point, "In considering the qualities of a fire-brick, chemically, the bases that have a fluxing action should be considered as a whole. A brick might contain more oxide of iron than it should do, yet on account of its being far from other bases, it might nevertheless be a good brick." We thus see that the number of the objectionable ingredients, as well as their aggregate quantity, has something to do with the result; besides a natural chemical combination, an artificial mixture might give the same analysis, and yet be very different as a fire-brick making material.

Those containing the largest percentage of silica, if otherwise pure (such as the Dinas of South Wales), stand best in the highest heats, but are liable to split up by sudden heating or cooling. A brick high in silica, yet containing a fair proportion of alumina, and comparatively free from alkalies and other impurities, is the one which combines in the highest degree infusibility and freedom from splitting; and is, consequently, found to be best suited for all such purposes as puddling, rolling, and forging, and the Siemens regenerator, where the great desideratum is precisely the combination of these qualities. A sample of clay from the Glenboig Star Mine was recently analysed by Riley, and, after being calcined, gave the following results : Silica 65.41 per cent; titanic acid, 1.33; alumina, 30.55; peroxide of iron, 1.7; lime, 0.69; magnesia, 0.64; potash, with a little soda, 0.55. Total 100.87 per cent.

To get a really good furnace, we must first procure the best materials for its construction; but after that, much depends upon how it is built. If we were as careful about the lines of our furnaces as we are about the lines of our ships, and as particular about the quality of the materials and workmanship employed, as the importance of the subject demands, we might, in many cases, double their duration, without waiting for the possible discoveries of the future. However anxious we may be for improvement, in the meantime we must make the most of the materials we possess, and of our present knowledge of the modes of manipulation.

The making of a fire-brick is like the making of a pin—the article looks a simple one, yet the process is complex and somewhat elaborate. Some of our most ingenious machines have the intelligence put into them at the beginning, and are afterwards almost self-acting; and while this can be done to some extent, in setting down a new fire-brick work, still in no process is close and careful attention more essential, if the best results are to be obtained. As in scientific investigation, the smallest gleam of truth has its value and its place, so in the workshop every little bit of ascertained fact has its value also, and if it gets its place, it will certainly bring its reward in the general result.

The fire-brick trade of Glasgow cannot lay claim to the antiquity which belongs to Stourbridge or Newcastle. It only dates back some forty or fifty years, when it was first started at Garnkirk, and is therefore comparatively young. But it is healthy, and even already well grown. For years past it has entered into friendly rivalry with the older seats of manufacture, and found markets in all parts of the world, and notably in the northern and midland counties of England, to which districts one or two of the best brands are sent in large quantities.

The quantity of fire-bricks annually made in the Glasgow district, which is almost exclusively comprised in the counties of Lanark, Renfrew, and Ayr, will amount in ordinary times to eighty millions. In addition to this there is manufactured an enormous quantity of sanitary pipes, gas retorts, and other articles in fire-clay, both useful and ornamental. Considerable quantities of fire-bricks are also made in the neighborhood of Edinburgh and in the counties of Stirling and Fife; but these I have not the means of estimating.

The fire-clays wrought in the neighborhood of Glasgow are situated geologically in the upper coal series and limestone series, taking the Roman cement as the dividing line, or, according to the Ordnance geological map, in the millstone grit. They are found at all depths, from the surface, opencast workings, to pits of forty to fifty fathoms. They are sometimes taken from lower depths, where coal is being wrought; but we do not find our best qualities in such positions. The workable seams vary in thickness from about three feet to thirty or forty feet. The process of fire-brick making is pretty much alike all over the West of Scotland, and, indeed, everywhere else, when fire-clay is the material employed; but, as it is necessary to be clear and connected, we will follow the process as applied at the Glenboig Star Works. The clay is there found 113 feet deep, and varies in thickness from six to nine feet. In descending the shaft, we pass through from twelve to twenty feet of floating whinstone, which covers a considerable part of the Glenboig district; under this are numerous beds of fire-clay and silicious rocks, some of them almost pure silica. The system of mining is what is called stoop-and-room, or pillar-and-stall. The workings are twelve feet wide, and the stoops left in are thirty feet square, excepting at the pit bottom, where they are much larger. The stoops may be cut through, and, when the proper time comes removed altogether. The clay, in its natural state, is very hard, and requires to be blown down with gunpowder. The average daily output of each man, unaided, is from four to five tons, according to the thickness or hardness of the clay. The clay is sent out in pieces about the size of good round coal. It is raised to a high pit-head platform, from whence it is run either to the crushing-mills direct, or to the bing, where it is exposed to the action of the weather.

When weathering is adopted, the extra labor of lifting and laying is involved, but the ease with which the milling is afterwards effected fully compensates. When the clay is mixed with "bullets" or nodules of iron, or any other visible impurities, weathering permits of these being picked out with ease. It disintegrates and softens the clay, so that a much solider body and smoother surface can be given to such articles as require these qualities.

In bricks for general furnace purposes we do not want a close texture. The brick must have sufficient flour in it to give it toughness and strength, that it may bear the rough shunting of our railways and the careless treatment which fire-bricks too often receive in shipping and trans-shipping. But that accomplished, our aim is to make them as rough and open in the grain as possible, that they may be the better able to resist high and variable temperatures.

The crushing and milling are effected by means of revolving pans, in which heavy iron-edge rollers run. The crushing pan is seven feet in diameter, and perforated in the bottom ; the crushing-rollers weigh upwards of three tons each. The wet pans are six feet in diameter, and the rollers weigh 35 cwt. each. They receive their motion from a large shaft running overhead, and connected with the fly-wheel of the engine.

The clay is first broken with hammers and shovelled into the crushing mill. The bottom of the pan has rows of perforations through which the clay is crushed. Scrapers, attached to the pan beneath, throw it into an iron box, from whence it is lifted about twenty feet by means of an endless chain, fitted with elevator buckets, which deliver it into a cylindrical riddle eight feet long and two and a half feet in diameter ; this is so placed that the riddled clay drops to a second set of elevators, while the pieces too large to pass through drop back into the crushing mill. This second set of elevators has two duties to perform. It either sends the fine ground fire-clay which is used as mortar in furnace building to an endless belt which carries it to the wagons on the railway outside, or the rougher brick clay to the tempering pans by means of a box sixty feet long, placed overhead. In this box there is a traveling chain fitted with clats by means of which the clay is dragged along. In the bottom of the box are four holes, to which four conductors are attached, one to each mill. These, from their position, are always kept full, and when the millman requires clay, he has only to draw a sluice at the lower end of the conductor, and the clay drops into the pan. He then turns on the water, and the mill is charged in a second or two.

For mortar clay a riddle with 196 meshes to the square inch is used, and for brick-clay one of twenty meshes. In preparing clay for glasshouse blocks, gas retorts, Bessemer tuyeres, and all large articles, a proportion of previously burned bricks or clay is added, to prevent cracking in the drying. Pug mills are generally employed for tempering where the clay is of a soft aluminous nature, but they are not suitable for hard, gritty, silicious clays. When ready for moulding, the clay is discharged into small tipping bogies, which are raised by means of a steam hoist to the upper floor of the drying stove. It is there run along a little railway, from whence it is dropped down through suitable openings to the moulders' benches. By this method one man delivers the clay to nine or ten moulders. It has also the advantage of taking the traffic off the drying floor. Once in the moulder's hands, it is rapidly turned into bricks. A good workman with his carrier will make 2500 bricks a day.

Solid brass moulds are used for regular sizes, but for odd kinds and the larger sizes wooden moulds are employed. Iron, zinc, and glass have been tried ; but hard brass has many advantages. The moulds are made a twelfth larger than the size of the burned brick, to allow for shrinkage. The face-board on which the brick is made is covered with thick plaiding, and the trade mark is fixed upon it, so that making and stamping are performed in one operation. Machinery is successfully employed in moulding common building bricks from stiff plastic clay, and also in the manufacture of dry or semi-dry compressed bricks from various materials ; but no machine has yet been made capable of taking well milled fire-clay as it leaves the pans, turning it rapidly into bricks, and delivering them square and sharp-edged on to pallet-boards.

When the brick is moulded by hand, the moulder discharges it on to a pallet-board, the carrier then places another board on the top of it, and between the two the soft brick is carried with safety, and deposited on edge on the stove floor, where it remains till hard and dry, when it is taken to the kiln.

The defects most common in fire-bricks, with the exception of soft burning, are produced in the stove, and it is here alone that soundness and finish can be given to them. If the stove floor is uneven, the shape of the brick is spoiled; and if too much heat is applied, the bricks are warped and cracked. Some clays are very liable to crack when too quickly dried; and where stoves are badly constructed, this occasions loss, and injures the quality of the brick to a serious extent. Where some are cracked through, others are partially cracked, and so on through all the stages of cracking, up to the sound ringing brick. Bricks of this description give also increased breakage in the kiln, and indeed in every stage of their existence.

To meet all this, a recently patented construction of stove is employed. The stoves are 120 feet in length, by 36 feet wide, and are fired from one end. The drying floors are entirely formed with cast-iron plates, each four feet by two feet, by $\frac{5}{8}$ of an inch. These are smooth and easily heated. Underneath the iron floor there is another, formed of fire-clay slabs, four inches and three inches thick, which runs from the furnace end to the middle of the stove, a distance of sixty feet.

The fires and hot flues are underneath the fire-clay slabs, and between the fire-clay slabs and the iron plates forming the upper floor there is an air-space of eight inches deep; this communicates with the outer air at the gable over the fires. Each flue has its own air-space. By this means the stove may be fired up so as to heat effectually the back end, while too much heat on the furnace end is prevented by the current of cold air passing between the two floors, till it joins the lower flue at the middle of the stove, carrying with it the superfluous heat of the furnace end, and utilizing it where it is required. Two such stoves, of the dimensions named, are turning out from 20,000 to 24,000 bricks a day. Every brick is ready for the kiln the day after it is moulded. By this system of drying, the cost is lessened, while the production for a given space is nearly doubled.

Various other methods have been tried, such as exhaust steam in pipes or flues, and hot air, in a variety of ways. In such cases shelving is generally employed, and this entails extra labor and expense. The method just described is, in every respect, to be preferred, particularly where large production and perfect regularity are required.

When dry, the bricks are wheeled to the kiln, where they are built up in chequered walls, each brick being nearly an inch apart. A kiln contains from 16,000 to 20,000 bricks; when filled, the doors are built up, and the fires kindled. The firing is done very gently at first, the furnace being open, and also the holes in the crown of the kiln; this is continued for two days, till the damp is completely steamed out of them, after which the crown of the kiln is carefully closed, the draught is connected with the chimney, and the kiln is put on full fire.

This takes other two or three days, during which time it is steadily brought up to a bright white heat, at which it is maintained till the necessary sink in the bricks has taken place, after which the firing ceases, and the kiln is gradually cooled down.

The kilns are built in pairs, back to back, and are fired from the one side across; the floor is not chequered, excepting over the flue which runs along the back, and through which the draught passes on its way to the chimney, either direct or through another kiln. The fires are on the hopper principle, something after the style of the Siemens' producer. They are supplied with hot air heated under the floor of the kiln, and in addition there is a good sized flue run from end to end of the kiln over the fires, through which cold air is supplied to each fire. Without this, the front of the kiln would become too hot; with it this is prevented, and the air thus introduced, after passing through the kiln, which acts as a kind of regenerator, combines at the back with the unconsumed gases, giving great evenness of burning and also great economy.

The Newcastle kiln is the one generally used, and here and there the old Scotch or Leeds kiln is to be met with, but these are too expensive in times of dear coal.

In conclusion, let us ask, How are we to meet the want, so frequently and urgently expressed, for "cheaper and better fire-bricks?" To some, cheapening suggests a reduction of price, but this would be no answer to the present demand. If the price were reduced until it disappeared altogether, and the quality of the brick remained unsatisfactory, the want would still be felt all the same.

What is required is a superior quality, so that the price, whatever it may be, will be found to be cheap when viewed in relation to the service rendered. Something may yet be done to economise fuel, and machinery may yet reduce the item of wages, and at the same time improve the condition of the workman; but if the requirements of modern metallurgy in this matter are to be fully met, it must be principally by the improvements of the quality of our furnace materials.

RETAINING WALLS.

By E. SHERMAN GOULD, C. E.

Written for Van Nostrand's Engineering Magazine.

The following is an attempt to place the calculation of ordinary retaining walls upon its simplest footing. As regards the higher and more exact investigations of the subject. I am well aware that there remains but little to be said, for in the pages of this magazine, and elsewhere, they have been developed with a completeness nearly, or quite exhaustive.

My aim is therefore, to follow the subject only so far as the most elementary processes of applied Mechanics will permit, but it will be found, I think, that these processes are quite adequate to the solution of even somewhat complex problems.

In designing a retaining wall, it is always easy to prepare a draft which will ensure stability; precedent and certain well-known formulæ, are sufficient guides for this, but what we want to get at by calculation is, the best *form* of cross-section. For instance: Given a certain volume of wall destined to sustain a certain mass of earth or head of water, should the wall be straight or battering? and if battering, should the batter occur on the exterior or interior faces, or both? In other words, what form of cross-section will give a maximum and *uniform* strength, so that the weight of the wall may act with the longest possible lever-arm, and that the wall may not be redundantly strong in some parts, and only just (or not) strong enough in others?

Now, though the minute and ultimate determinations of these questions may demand the aid of the higher mathematics, their approximate and, in ordinary cases, sufficient solution may be easily reached by far simpler processes.

Setting aside, as foreign to our present purpose, the exceedingly important consideration of foundations, there are three ways in which a retaining wall may fail. First it may fail by overturning; secondly, by sliding, and third by a combination of the above.

Of these, the last is probably the most frequent. The second rarely, or never occurs except in the case of a wall resting on a slippery bottom, while the first is a case of not infrequent occurrence, and is in fact what would commonly happen to a too thin wall, well laid up with good materials.

It is obvious that we can reach by calculation, only two, namely, the first and second, of these cases. But this is quite sufficient, for if we prove our structure to be safe against overturning *or* slipping from a single force, it must be safe against overturning *and* slipping from the same.

It is usual, in designing a retaining wall, to calculate only its tendency to turn, as a body, around its foot, or slide, as a body, upon its base. This is not sufficient to ascertain if the before-mentioned requirements are fulfilled. In a straight wall, of equal thickness throughout, indeed, this calculation will be *safe*, for, as we shall presently see, the lowest course is the weakest part of an earth-sustaining wall, but the upper courses will have redundant width; and in the case of a battering wall, especially if the battering faces be curved, the upper courses may not be sufficiently deep for safety, though the lowest course may.

It must be born in mind, that all these calculations are subject to certain limitations of accuracy, arising from the nature of the construction. Thus, a certain part of a given wall may be shown by calculation to be that suffering the maximum stress, and yet, from extra good workmanship and material at that particular point it may be the last place at which the wall would fail, and *vice versa.* These circumstances cannot of course be taken account of in the design; the wall must be designed on the assumption of equally good workmanship throughout, and it falls to the duty of those intrusted with the execution of the work to see that this assumption is vindicated.

If we dig a trench, or other excavation with vertical sides, we see that the earth, sooner or later, and to a greater or less extent according to the nature of the soil, crumbles and falls until it assumes its *natural slope.* All that is not in equilibrium has then come away, and the sides have assumed their permanent state of rest. Now the object of the retaining wall is to hold up the unequilibriated mass of earth which would otherwise be detached, and fall. In order to ascertain what the extent of this mass might be, let us consider what would be the result of suddenly and bodily removing the straight retaining wall A, Fig. 1: A portion of the earth would fall,

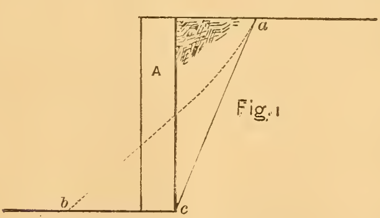


Fig. 1

and sooner or later assume some such slope as that shown by the dotted curve *a b.* It is evident, therefore, that the wall has to sustain the pressure of some such prism of earth as might lie between its inner face and the imaginary slope *a c.* It is shown mathematically, but by reasoning from more subtle considerations than those involved in the above rough illustration, that the true prism of pressure lies between the retaining wall and a line drawn from its foot, called the line of rupture, inclined to the vertical at an angle equal to one half of the angle of natural slope. (*Note*—The fact that these are the true boundaries of the prism of pressure, receives corroboration by a reference to hydrostatic pressure. In this case the angle of natural slope would be 90°. Half of this, or 45°, would then give the line of rupture. Calculating the prism of pressure from this datum, we get the same as that reached by other, and undeniably correct methods of calculation).

This prism acts against the wall like a wedge driven vertically downward by its own weight, and moving, or tending to move along the sloping surface of the line of rupture. Thus, in the prism *a b c* (Fig. 2) tending to slide downward

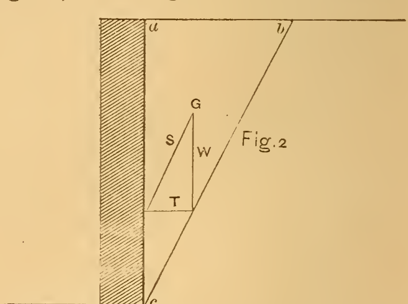


Fig. 2

along *c b*, we have the weight W = radius, acting from the center of gravity G of the prism, and striking the inner face of the wall along the secant S of the angle of rupture, at one-third of the height of the wall from its base (because G is at one-third of the altitude of the triangle *a b c*). The weight, thus acting, tends to thrust the wall out with a force represented by the tangent T of the angle of rupture. *The pressure tending to cause sliding along the base of the wall is therefore equal to the weight of the prism of pressure a b c multiplied by the tangent of the angle of rupture a c b; and the moment tending to produce overturning around the foot of the wall, is equal to* *the above multiplied by one-third of the vertical height of the wall.*

Fig. 3 shows a rectangular wall nine feet high and three feet thick, sustaining

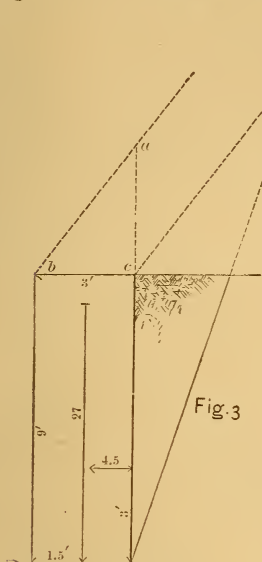


Fig. 3

a bank of earth the density of which we will suppose equal to that of the material of which the wall is built, and of which the natural tangent of the angle of rupture is equal to 0.333: this tangent corresponds to an angle of about $18\frac{1}{2}°$, which in turn corresponds to a natural slope of about 37°. Considering a foot's length of wall, and taking the weight of a cubic foot of earth or wall as unity, we have a pressure of $\frac{13.5}{3} = 4.5$ tending to produce slipping at the base, and a moment of $4.5 \times 3 = 13.5$ tending to produce overthrow.

Apart from the cohesion of the cement and the bond of the material, the resistance of the wall to slipping is its friction, which depends directly on its weight. As, in the comparison we are about to make, the relative frictions are all we care about, we will entirely ignore the co-efficient of friction, and consider only the variable factor, namely, the weight. We have in the present case a weight of wall equal to $9 \times 3 = 27$, giving a resistance as 6 to 1 as compared with the pressure tending to produce sliding.

The resisting moment of the wall to overthrow, neglecting cohesion of cement, is the weight of the same multiplied by the distance of the center of gravity, from the point around which it tends to turn. It is in the present case $27 \times 1.5 = 40.5$, or as 3 to 1, as compared with the overturning moment.

We have thus obtained the forces and resistances tending to produce or prevent sliding and overthrow at the base of the wall. If now we consider these forces and resistances as applied to the upper half of the wall, we will find that while the resistances are diminished by one-half only, the force tending to produce sliding is reduced to one-quarter, and that tending to produce overthrow to one-eighth, of their respective values as applied to the whole wall, and that therefore the wall is badly proportioned in that the destructive and resisting forces do not diminish in the same ratio.

Transforming the rectangular section of wall into the equivalent triangle shown in Fig. 4, we have the same de-

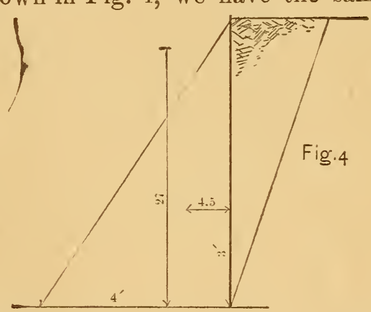


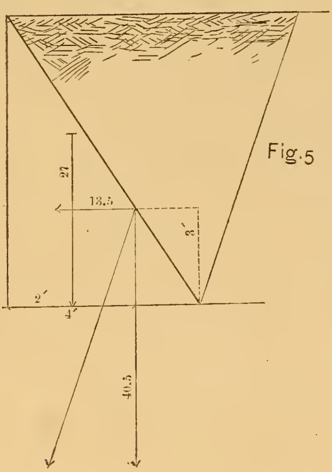
Fig. 4

structive forces as before, and the same resistance to sliding at the base, *i. e.* as 6 to 1, while the resistance to overthrow at the base is increased from the fact that the center of gravity of the wall has been thrown further away from the point of rotation; it becomes $27 \times 4 = 108$, or as 8 to 1, compared with the moment tending to produce overthrow.

If, as before, we now consider the condition of stability of the upper half of the wall, we find as before the destructive forces decreased respectively to $\frac{1}{4}$ and $\frac{1}{8}$ of their whole values, while the resistances are diminished in exactly the same ratio. We may, therefore, conclude that the wall is well proportioned, and we see moreover, that while its resistance to sliding, due to its friction, remains the same as in the rectangular design, its resistance to overthrow has, by a mere change of form, been increased as 8 to 3. It must be borne in mind, too, that the above resistance to sliding is only that due to friction. The bond of the material and the cohesion of the cement are also resisting elements, and the wall shown, Fig. 4, has a double width of base and, consequently, as far as bond and cohesion are concerned, a double resistance to sliding at the base.

If we suppose the density of the two walls, Figs. 3 and 4, doubled, making their weight 54, and carry out the calculation, we find that the ratio of eight to three remains unaltered.

Let us now consider the transformation shown in Fig. 5. With an equal

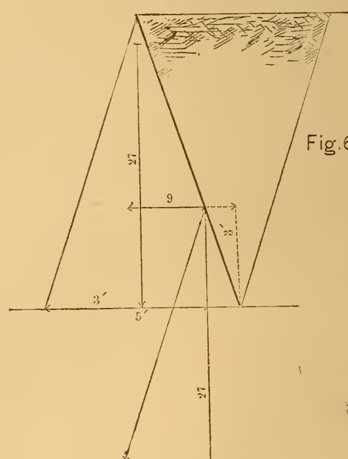


weight of wall, we have here a weight of earth of 40.5, which, it must be observed, increases the stability of the wall at the same time that it increases the pressures against it.

Thus, we have a pressure tending to produce sliding of 13.5, with a combined weight of wall and earth tending to resist it, of 67.5, or as 5 to 1; and an overturning moment of 40.5, with a resisting moment due to weight of wall and earth with their respective leverages, of $27\times2+40.5\times4=216$, or as 5.33 to 1: a marked inferiority in both respects to the previous design. Doubling the weight of wall, gives a resistance to sliding increased to 7 to 1 only, and a resisting moment increased only to 6.66 to 1, showing that the ratio of stability increases much less rapidly than the weight of wall, unlike the previous examples where it increased as the weight of wall.

One important fact must, however, be borne in mind, respecting walls which, like Fig. 5, have the batter toward the bank, viz.: under certain circumstances overturning is impossible, because the overturning moment is derived directly from the weight of earth, and in such designs this weight forms at the same time a moment in favor of stability. In the above case, the moment of the horizontal component of this weight, tending to produce overthrow is $13.5\times3=40.5$, and the moment of the vertical component tending to prevent it, is $40.5\times4=162$. Clearly, in this case, and with these angles of batter and rupture, overturning is impossible, and the wall can only yield by sliding. At the same time the pressure on the foundations is increased.

In Fig. 6 we have the same ratios of resistance to sliding and overthrow as in Fig. 4. Doubling the weight of wall, however, gives increased ratios of stability of only 9 to 1 and 11 to 1 against



sliding and overthrow respectively, instead of 12 to 1 and 16 to 1, as in Fig. 4. The same remark as to impossibility of overturning, as was made for Fig. 5, holds good here.

Both this and the preceding design are well proportioned as regards uniformity of resistance through their whole heights.

The above figures are to be considered as diagrams only, and not as representing proper designs for retaining walls. For instance, in an actual wall, the section would never be triangular but trapezoidal, and in the case of a wall battering toward the bank, the sloping face would be stepped, instead of showing an even surface.

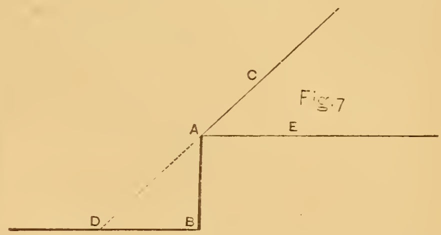
In the case of sections presenting a vertical face to the bank, no account has been taken of the downward pressure of the earth, friction against the back of the wall having been entirely disregarded. In practice, however, the back is left rough, and from its friction and hold on the earth would utilize a portion of the downward pressure in the interest of stability.

A wall tipped over toward the bank at an angle equal to the angle of pressure would sustain, theoretically, no thrust whatever. As, however, the angle of pressure must be considered as constantly varying with the hygrometric and other conditions of the soil, and is at all times more or less uncertain, a wall so built might, and probably would, be subjected to a varying uplifting stress, more injurious than a varying horizontal or downward one. Very admirable walls have been built upon this principle, and they well merit study. It would seem as a condition of primary importance, that, under no circumstances, should the wall be tilted over its center of gravity, so as to depend for support upon the earth behind it.

Buttresses, counterforts, relieving arches, etc., form subjects for separate investigation, and cannot now be considered. One word, however, may here be said regarding counterforts. Though not increasing the moment of stability of the wall to the same extent as buttresses, they notably diminish the moment of overthrow, by reducing the volume of sliding earth by the space which they themselves occupy, and by the side slopes which their friction generate, and, moreover, break the continuity of pressure, making it act only at detached points.

It is a matter of remark, that retaining walls generally possess a greater actual stability than calculation would indicate. When this occurs, it shows that the destructive forces have been over-rated. Indeed, it is only necessary to observe the length of time which many unprotected banks take before assuming their permanent natural shape, to be convinced of the great margin of safety included in the usual supposition that the pressure of the earth is applied instantaneously to the wall, and over its entire length.

Walls sustaining a surcharge of earth, *i. e.* walls placed at the foot of a sloping bank, involve a very intricate problem. One view of the question would seem to indicate clearly that the wall undergoes no greater pressure from the surcharge than if the bank of earth were terminated by a horizontal plane level with the top of the wall. Thus, let A B, Fig. 7,



represent a wall at the foot of a slope extending indefinitely in the direction A C. If the wall were removed, and the slope continued along the dotted line A D, the bank would of course stand, the angle C D B, being supposed to be as small as or smaller than the angle of natural slope. Consequently the necessary sustaining power of the wall must be equivalent to the prism of earth of base A D B. If now we suppose all the bank removed above the horizontal line A E, level with the top of the wall, we still find the prism A D B, necessary to sustain the bank E A B. That is, in both cases of surcharge and no surcharge, the same force is necessary and sufficient to sustain the bank.

This reasoning seems conclusive, and yet few engineers would probably feel justified in making no provision for an increased pressure due to the bank C A E. At all events, the pressure on the wall A B would be that due to the mass of earth which would detach itself if the wall were suddenly removed, and perhaps the safest plan is to suppose the line of rupture produced till it intersects with the slope of the surcharge, as shown by the dotted lines in Fig. 3, and consider this increased prism as that pressing against the wall. Should the surcharge extend to the front face of the wall, as shown by the lines *a b* Fig. 3, the weight of the prism *a b c* may be considered as added to that of the wall.

It will be interesting now to investigate some of the simpler forms of walls designed to sustain the pressure of a head of water. This pressure acts somewhat differently from that of a bank of earth, but as regards calculation, has the advantage of being determinate both in force and direction.

Let Fig. 8 represent the vertical section of a dam or reservoir wall, 12 feet by 12 feet. Let a cubic foot of water

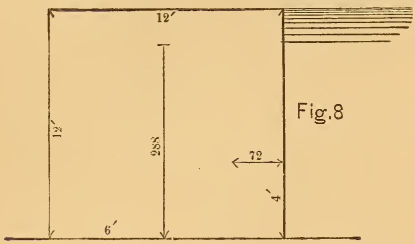


Fig.8

be the unit of weight, and suppose the density of the wall to be double that of the water. Taking always a foot's length of wall, there is a pressure upon it equal to the weight of a column of water of 12 square feet base, 6 feet in height, acting perpendicularly to the inside face of the wall, and at one-third of its height from the base. The overturning moment is then $12 \times 6 \times 4 = 288$. The resisting moment of the wall is, by our supposition, regarding its weight, $12 \times 12 \times 2 \times 6 = 1728$. Ratio of moments, $\frac{288}{1728}$, or as 1 to 6. The pressure tending to produce sliding at the base, is 72. Weight of wall resisting same, 288. Ratio, 1 to 4.

Transforming the rectangle of Fig. 8 into the equivalent triangle Fig. 9, we

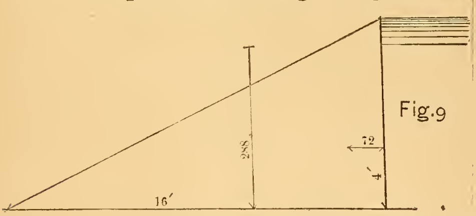


Fig.9

have overturning moment 288, as before, resisting moment, 288×16. Ratio, 1 to 16, or, as compared with previous ratio, 8 to 3. Resistance to sliding as before, with, however, the advantage of greater depth of bed.

If, now, we calculate the destructive and resisting force upon the upper half of Fig. 8, we find that while the forces tending to produce sliding and overturning, are reduced respectively to one-fourth and one-eighth of their whole values, the resistance to both is only diminished to one-half, showing a redundant strength in the upper courses, as compared to the bottom course.

Calculating in the same way for Fig. 9, we find the destructive and resisting forces diminish in the same ratio, thus indicating a well proportioned design.

In the equivalent section, Fig. 10, we

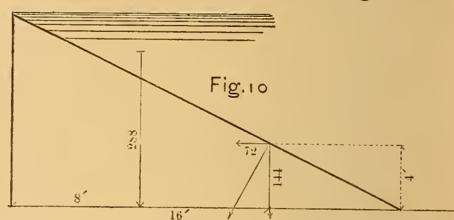


Fig.10

develop a vertical component tending to increase the stability of the wall, at the price, however, of an increased pressure on the foundation. When a certain head of water presses upon an inclined surface, as in Fig. 10, its horizontal thrust is given by the vertical projection of the submerged surface, multiplied by half the head, and the vertical pressure is given by the horizontal projection of the submerged surface, multiplied by half the head. We have thus, 72 and 144, respectively, for these two pressures. They give, a sliding pressure of 72, with a resistance to same from weight of wall and water of 432, ratio 1 to 6; and an overturning moment of 288 with resisting moments of 288×8

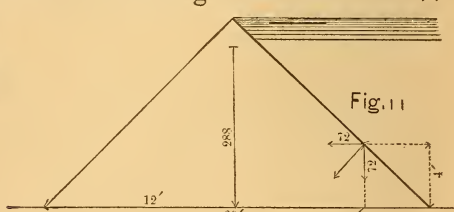
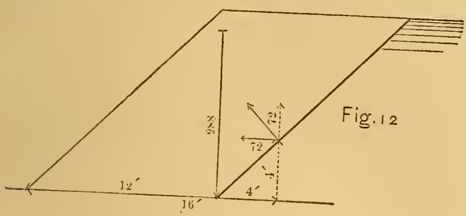


Fig.11

$+ 144 \times 16 = 4608$, ratio 1 to 16. Though we have calculated the overturning moment and the resistance to it, it is evident that the wall shown in Fig. 10 could never overturn, but could only be destroyed be crushing or sliding. Its resistance to the latter is greater than in either of the previous designs.

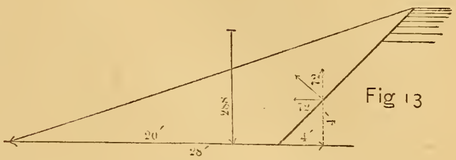
Passing to the design of Fig. 11, we

have, tendency to slide, 72, resistance to same, 360, ratio 1 to 5. Overturning moment, 288, sum of resisting moments,



4896, ratio 1 to 17. Here again, overturn is impossible, on account of the downward pressure of the water.

In such designs as those shown in Figs. 12 and 13 there is a tendency to



"blow up," from the vertical component of the water pressure. The data given on these figures, will suffice for their calculation.

CORROSION OF BOILERS.*

By Mr. F. J. ROWAN.

From one or two causes, corrosion has been found to attack the exterior surfaces of boilers, and eventually to work considerable damage. This, however, is a simple matter, as the action in these cases is easily preventible.

Thus, in the case of land boilers, careless setting in too much lime, has produced bad effects—the part of the boiler shell exposed to the, probably impure, lime having been eaten away to a large extent.

Setting the boilers upon a damp foundation without proper provision for draining, has also resulted in rapid destruction, whether the moisture reached the boilers through the lime of the setting or through the ashes.

Both marine and land boilers have been seriously corroded by ashes when cold having been carelessly allowed to remain in contact with the iron. The ashes contain a considerable quantity of alkaline salts of some strength, and with damp drawn from the bilge water in vessels, or from the ground ashore, or by deliquescence from the atmosphere, these salts have been enabled to attack the iron vigorously.

It has also been found by S. Dana Hayes (*Chem. News*, vol. xxx., 153, *Jour. Chem. Soc.*, vol. xiii., p. 294), that the soot in tubes and flues has become charged with pyroligneous acid, where wood has been freely used in lighting fires, or large quantities of coal have been charged at a time; and that this combination has caused corrosion. The same result has been caused by the soot retaining fine dust of ashes, and in consequence also sulphur acids, derived from pyrites in the coal. A case of this kind is also published by J. W. Chalmers Harvey, in *Chem. News*, xxxii., 252, *Chem. Soc. Jour.*, No. clxi., p. 796.

It is sufficient, however, to point out these causes, for they suggest their own remedies. Care in preparing and completing the setting, in cleaning flues and ash pits, and in firing being all that is necessary to prevent corrosion from them.

The injudicious use of brass cocks and connections bolted or fastened directly to the boiler shell, has often resulted in corrosion from galvanic action at the places where the two metals come in contact. This action proceeds more rapidly when a little leakage of water takes place at the joint or connection.

The operation of corroding forces in the interior of boilers, is, however, far more serious and baffling. Yet even these forces may be reduced to submission, but they demand study in the becoming spirit of patient enquiry.

* A paper read before the British Association at Glasgow.

Many investigations of these forces and their actions have been made, and it is advisable to review these before attempting to deal with the subject from an engineering point.

One of the first to publish experiments and trials connected with the corrosion of metals was the late Prof. Crace Calvert, who exposed iron and steel (with other metals) to the action of sea-water, of natural fresh water, and of distilled water, with and without air. He also submitted iron and steel to the action of various gases, with and without moisture, and to that of various acids. In general the results obtained by him showed that steel and then iron were most rapidly corroded by sea water when simply immersed in the sea for a time. (105.31 grammes of steel and 99.30 of iron being dissolved from plates of forty centimeters square by immersion in the sea for one month.) Also that iron immersed in water containing carbonic acid oxidised rapidly with escape of hydrogen gas, which led him to suppose that some galvanic action had part in the operation. He may, however, have meant merely thus to designate the decomposition of a part of the water by which oxygen was dissociated and combined with the iron under the influence of the carbonic acid. The corrosive action of carbonic acid was corroborated by his experiments with gases, for when bright blades of steel and iron had been exposed for four months to the action of various gases he obtained the following results: There was no oxidation with dry oxygen: with damp oxygen, one blade only out of three experiments was slightly oxidised: no oxidation with dry carbonic acid; with damp carbonic acid there was a formation of white carbonate of iron on the blades; no oxidation with dry carbonic acid and oxygen, but very rapid oxidation with damp carbonic acid and oxygen. He also found that distilled water which did not contain air or gases was without corrosive action upon iron, a bright blade which was immersed in such water having become in some days merely here and there spotted with rust. It was found that at these spots where oxidation had taken place, there were impurities in the iron which had induced galvanic action, "just as a mere trace of zinc placed on one end of the blade would establish a voltaic current."

An analogous action of distilled water with and without air was observed in his experiments with lead—200 litres of distilled water without air having dissolved during eight weeks only 1.829 grammes from a surface of 1 sq. meter, while the same quantity of distilled water aërated dissolved in the same time 110.003 grammes.*

These investigations were made the basis of an enquiry by Mr. W. Kent, of the Stevens Institute of Technology, into the corrosion of iron in railway bridges in the U. S., and by their means he was enabled to arrive at a satisfactory demonstration of the causes of the action. His paper was published in the *Engineer*, in Aug., 1875.

Recently, some of Calvert's results have been verified by A. Wagner, who publishes (in *Dingler's Polyt. Jour.*, 218.70-79) an important paper on the Influence of Various Solutions on the Rusting of Iron. Distilled water free from air does not appear to have been tested, but with air freed chemically from all carbonic acid, a slight rusting was noticed, the water, however, soon becoming saturated with its proper quantity of iron. The action of carbonic acid (or carbon dioxide) observed by Calvert is also noted, and the fact noticed for the first time that the presence of chlorides of magnesium, ammonium, sodium, potassium, barium, and calcium in the water largely increases the production of rust, while this important fact also appears from his results, that the corrosive action of all these substances is considerably increased by the presence of air and carbonic acid in solution. Chloride of magnesium of all these salts is the most active agent when alone in corroding the iron, but combinations of chloride of magnesium and carbonate of lime, of chlorides of barium and calcium, and of chlorides of sodium and calcium have also considerable corrosive action.

This to some extent corresponds with

* Sir R. Christison has made investigations into the action of water on lead (*Chemical News*, vol. xxviii. 15), but seems in his conclusions not to have distinguished between distilled water and pure natural waters, merely comparing them with respect to *purity*. Yet the fact that he always found carbonate of lead formed by the action of the purest waters suggest that the action was due to the presence of gases in solution and not to the water itself.

the fact observed by Mr. John Gamgee, as a difficulty which he had to encounter in connection with the continuous freezing of water for his "Glaciarium," viz, that the brine solutions used as media of congelation act destructively upon the metallic surfaces of the pipes or channels through which they are conveyed. (*Engineering*. vol xxi., page 226.)

Wagner, however, has also noticed that while chloride of magnesium solution in the absence of air attacked iron at a temperattre of about 100° Cent., the chlorides of sodium, potassium, barium and calcium were without action under these circumstances. This author also notices the fact, the observance of which is ascribed to Mr. Young, of Kelly (in a paper read by Mr. James R. Napier before the Phil. Society of Glasgow, Dec. 16th, 1874), viz., that the presence of an alkali in water protects iron and prevents rusting. In consequence of the great importance of his results, I give two tables of figures (from the four contained in his paper) representing some of them :

No.	Solution.	Percentage of loss of weight in one week.	
		With air free from CO_2.	With air and CO_2.
1	Freshly distilled water	0.83	1.53
2	Containing $Ba\,Cl_2$ and $Ca\,Cl_2$	1.63	1.46
3	Containing Na Cl and KCl	1.20	2.03
4	Containing $Mg\,Cl_2$	1.40	1.85
5	Containing NH_4 Cl	1.29	2.16
6	Containing $K(OH)_2$	—	—
7	Containing $Na\,CO_3$	—	—
8	Containing sea water	1.26	1.02
9	Containing sea water, evaporated, and oil 5 drops	0.47	0.73

No.	Solutions.	Boiling in contact with air then and while cooling. Percentage of loss of weight—					
		1 week	2 wks.	3 wks.	4 wks.	5 wks.	6 wks.
1	Distilled water	0.44	0.82	1.15	1.53	2.02	2.46
2	Flask half-filled with distilled water —*i.e.*, more air	1.01	1.62	2.75	3.68	4.53	5.18
3	Containing $Ba\,Cl_2$ and $CaCl_2$	0.66	1.33	1.57	1.82	2.03	2.27
4	Containing Na Cl and KCl	0.84	1.47	2.15	2 57	3.04	3.41
5	Containing $Mg\,Cl_2$	1.31	1.91	2.20	2.49	2.76	3.05
6	Containing $Mg\,Cl_2$ and excess of $Ca\,CO_3$	0.89	1.54	2.08	2.46	2.97	3.27
7	Containing NH_4 Cl	1.15	1.86	2.56	3.16	3.66	4.16
8	Containing $K(OH)_2$	—	—	—	—	—	—
9	Containing $Na\,CO_3$	—	—	—	—	—	—
10	Sea water	0.43	0.65	0.70	0.75	0.97	1.24
11	Sea water and $Ba\,Cl_2$	0.15	0.46	0.69	0.92	1.08	1.23
12	Sea water and 10 drops oil	0.59	0.59	0.62	0.72	0.83	0.93

I quote here an important experiment made by him on the effect of chloride of magnesium on iron at boiling temperature.

Two grammes of neutral magnesic chloride were introduced into a strong tube in which weighed pieces of iron were placed; boiling distilled water was added, and the tube sealed up while steam was issuing. It was then kept at 100° Cent. (212° F.) for six weeks, and after cooling was opened. Gas was evolved on opening it; the iron was black and had lost 0.39 per cent. in weight, and the solution when filtered contained chloride of iron (ferrous chloride). (*Dingler's P. J.*, ccxviii. 70-79. *Chem. Soc. J.*, No. clx. p. 522.)

Still another valuable contribution to our knowledge of this subject comes to us from Germany, in the results of an examination of the effects of condensed water containing grease on boilers which were fed with it, by Stingl, an author who also proposed and successfully carried out a method for the purification of that water.

The water was evidently condensed by means of an injection condenser, as salts of lime and magnesia were present in small quantity in the condensed water. These salts, in presence of grease, at a temperature not exceeding 60° to 70° C., form lime-soap—part of the lime salts being, as has already been shown, rendered insoluble at these temperatures. The lime-soap, under the influence of a higher temperature, partially decomposes into free fat acid and an organic substance which is reducible by further heat, yielding a carbonaceous residue. This substance is a kind of basic lime-soap which adheres to the boiler surfaces, while the acid, which is usually oleic acid, attacks and dissolves the iron. In the crust the fat acid is recognised by the addition of hydrochloric acid, the separated organic mass being afterwards shaken with ether. The boiler crusts have usually a dark color, partially due to the presence of oxide of iron, partly to separation of carbon from the fat acid partially decomposed. Even if lime and magnesia salts are present in very insignificant proportion, the presence of grease is none the less injurious, as with saponification under great pressure, a very small quantity of lime suffices to occasion the splitting up of a neutral fat into free fat acid and glycerin; with low pressure it is not doubted that the same decomposition occurs, though more gradually.

A sample of very soft water (6° of hardness) depositing very little crust, was submitted to the author of that paper, as a boiler in which it had been used was completely destroyed after three years' work. This water had a milky appearance, and contained 0.212 parts of fat in one litre.

He also quotes the case of the corrosion of a gasometer, the cistern of which had been luted with greasy condensation water. The gasometer would have lasted twenty or thirty years had ordinary water been used, but in the circumstances mentioned, that part of it exposed to the water was corroded through after four years.

The destructive action of the oleic acid on the oil-pumps used in stearin candle manufactories is also alluded to. And the following details are given of an interesting case of boiler corrosion, with accompanying incrustation, and of the means used to overcome the destructive action. The condensed water from two steam engines, respectively of 300 and 100 horse-power, was used to feed a steel boiler of the Cornish design. After only three weeks' firing, water began to leak into the tubes, and shortly after the boiler had to be stopped for examination and repair. A deposit on the upper part of the tubes, from eight to eleven mm. thick, was found. The water had an opalescent appearance, at once removed by ether, which the author recommends as a good qualitative test for the presence of grease in water. The following is the result of analysis of the condensed water, which was obtained at a temperature of 40° to 50°.

	In 10,000 parts.	
Calcium carbonate.........	1.3091	"
Magnesium carbonate... ...	0.6930	"
Calcium sulphate...........	0.3158	"
Magnesium chloride........	0.0134	"
Sodium chloride............	0.1200	"
Ferric oxide and alumina...	0.0241	"
Silica..........	0.0023	"
Organic matter....	0.4138	"
Total...	2.8915	"

The crust deposited from this water had a dark greyish-brown color and was friable; but when pulverised it was difficult to wet with water. It effervesced strongly with hydrochloric acids, a black fatty mass being left floating on the surface of the acid, which shaken with ether yielded thereto about 5.19 per cent. of a brown oil. The residue insoluble in hydrochloric acid was washed with ether to remove fat, dried at 100°, weighed and ignited. The following shows the full analysis :

Calcium carbonate.......	51.42	per cent.
Magnesium carbonate....	11.30	"
Magnesium hydrate......	3.90	"
Calcium sulphate........	6.63	"
Ferric oxide...........	12.75	"
Alumina....................	0.31	"
Silica.......................	0.34	"
Fat acids.................	5.19	"
Combustible matter.. ...	8.46	"
	100.30	

In order to purify the water, the calcium carbonate and part of the magnesium carbonate, with all the grease, were removed by precipitation and subsequent filtering. The fat particles were removed by being enveloped by the precipitated calcium carbonate, which mechanically retained them on the filter, the reaction being favored by suitable temperature and intimate mixture previous to filtering.

The water then contained in	10,000	parts.
Calcium carbonate..........	0.1773	"
Magnesium carbonate.......	0.4135	"
Calcium sulphate...........	0.2068	"
Magnesium chloride........	0.0108	"
Sodium chloride............	0.2351	"
Silica..........	traces.	
Ferric oxide and alumina...	traces.	
Organic matter.............	0.1512	"
Total..................	1.1947	parts.

No grease could be detected in the filtered water, which was then used in the same boiler, after being repaired, for three months, when the deposit on the tubes was found to amount to a layer of only the thickness of a sheet of paper and almost wholly consisted of gypsum, and easy to remove. The whole amounted to only five kilometers in weight after three months' steady work. It was a loose greyish-brown mass, the following showing the analysis :

Calcium carbonate.......	19.30	per cent.
Magnesium carbonate....	1.26	"
Magnesium hydrate......	45.02	"
Calcium sulphate	15.12	"
Ferric oxide.............	9.43	"
Silica......................	2.04	"
Organic matter (insol. in ether)..................	7.35	"
Fatty matter.............	traces.	
	99.52	

To purify such water as the abovenamed for high pressure boilers, a mixture of lime-water and caustic soda solution is recommended, as this not only removes fat acids but also removes the magnesia, which forms with gypsum hard incrustations at high temperatures. (*Dingler Polyt. J.*, ccxv. 115-121, *Chem. Soc. J.*, vol. xiv., sec. 2. p. 132.)

In a letter on the corrosion of boilers, addressed by me in October, 1874, to the Editor of *Engineering* (and published in that paper on October 23, 1874), reference was made to the Report on Corrosion of the Tubing of two of Rowan & Horton's Patent Boilers, by Mr. Thomas Spencer, an analytical chemist. Starting from the slender basis afforded by the examination of water mains in two cases of internal corrosion of these, where a very pure natural water was conveyed through them, Mr. Spencer argued that the corrosion in these boilers was due to the use of distilled water, which alone was used in them, but which he confounded with pure natural water. In the absence of any well ascertained facts as to boiler corrosion, his opinion was accepted as sufficiently explanatory of the action; but, as is often the case with half-knowledge, that which was true in his investigations, was rendered indistinct by crude conjectures. In consequence of this, in the letter referred to, and generally in all published opinions emanating from engineering sources which I have seen, neither the great difference between genuine distilled water and pure natural waters—viz., the quantity of air and gas which is invariably held by the latter—has been properly weighed or even acknowledged, nor has the only point of similarity between the distilled water from surface condensers known on board steamers and pure fresh water—viz., that there is always some air present in the former—been noticed or allowed for. In the letter referred to, I regret that I was misled into confounding distilled water with Loch Katrine water, having in view merely purity, and not considering the presence of air or gases.

In considering now some examples of boiler corrosion, I shall adopt the arrangement already used in the section on Incrustation, viz :

1. Land boilers using natural fresh waters; and,
2. Marine boilers.

1. From what has been before us in connection with Incrustation, it is plain that it is in those land boilers only which are fed with pure natural waters that we are likely to find Corrosion at work. Where lime salts are present, a crust is formed, and the metal surfaces of the interior of the boiler are thus kept from contact with the water and any corroding ingredient in it. The special inconveniences of such crust formation we have already considered. Highly chalybeate waters, although not depositing a crust, do not seem to act injuriously. A case is mentioned in Mr. Jas. Napier's paper in *Proc. Phil. Soc. G.*, demonstrating this. There may, however, be some material forming part of the crust, or adhering to it, which suffers decomposition in contact with the heated iron, and, as a consequence, attacks the metal. This is the case with crusts formed with fat or greasy substances, as in the instance already quoted in the paper by Stingl.

We have, in this district, ample opportunity of proving the effect of very pure fresh water upon boilers, because there are few natural waters of greater purity than that from Loch Katrine, with which various manufactories in and around this city are supplied.

The water formerly supplied to Glasgow having been calcareous, it has been found that boilers which used it for some time, have not suffered from corrosion when subsequently fed with Loch Katrine water—the explanation of this being the fact that the thin coating of lime which these boilers had acquired acted as an efficient and permanent protection.

Where, however, owners or managers have been very zealous in removing by mechanical or chemical means every trace of that crust in order to get the full benefit, as they have thought, of the pure water, the result has been different and "the full benefit" has often been of a kind to perplex them. When also new boilers have been started from the first with Loch Katrine water corrosion has been more or less rapid, and considerable trouble and inconvenience have been caused thereby.

These facts find illustration in many manufacturing establishments around. I have been informed, amongst others, of a boiler attached to a mill in Bridgeton where every care was taken to remove all scale before introducing Loch Katrine water, and the millowners were chagrined by finding their boiler quickly suffer from corrosion.

In an engineering work at Port-Dundas (Rowan & Co.'s), one boiler which had wrought upon a supply of the former calcareous water, and was latterly supplied with Loch Katrine without being scaled, continued to work for some years without showing symptoms of distress from corrosion. In the same works, however, a range of new boilers, put down after the introduction of the pure water, suffered so severely as to require constant repairs at tubes, and an entire new set of tubes (of between forty and fifty in each boiler) in a comparatively short time. In another engineering work on the south side of the city (A. & W. Smith & Co.'s), the mains hop boiler was worked for three or four years without suffering corrosion with Loch Katrine water, after having worked previously for seven or eight years with the former Glasgow water. When a new boiler was substituted for this old one, although the new one was subjected to precisely the same conditions as those its predecessor wrought under for some years without trouble or difficulty, it was found to the consternation of the proprietors that the new boiler was corroding away so fast as to suggest that a third boiler would be required very soon. Until the presence and effect of the lime coating in the former boiler were pointed out, it was impossible for them to understand how one boiler should be able to use Loch Katrine water without damage, while another similarly worked should suffer in so short a time.

In the former of these two examples no condensed water was fed into the boilers, as they were working in connection with high pressure atmospheric engines and other machines; consequently there was no grease or other corrosive agent introduced into them, and thus the corrosion could be traced directly to the water. In the latter one, a part of the condensed steam was collected in the feed cistern, and a considerable quantity of grease thus found its way into the boiler, thus aiding the corrosion somewhat. Steps were at first taken to exclude this grease from the boiler but the corrosion afterwards proceeded—large quantities of oxide of iron being removed from the boiler—until means were adopted to overcome the action.

The following is the result of the analysis of the water made during July, and published by Prof. Mills, who informs me that it represents a fair average of the quality of the Loch Katrine supply:

	In 100,000 parts.
Total solid impurity	3.16
Organic Carbon	0.110
Organic Nitrogen	0.033
Ammonia	—
Nitrogen as nitrates and nitrites	—
Total combined Nitrogen	0.033
Chlorine	0.70
Hardness	0.48

The report also bears that the water was pale brown in color and contained traces of fibrous matter and muddy particles, and that the general condition was very satisfactory.

Nothing contained in the water as impurity can account for its destructive action; but the fact that it contains seven to eight cubic inches of gas (of which about three cubic inches are oxygen) to the gallon in solution, coupled with the investigations already quoted in this paper, as to the effect of distilled water without gas and of water containing gas, makes all plain. The corrosion is due to the action of the carbonic acid and oxygen held by the water, and the action is all the more rapid, from the absence from the water of any mineral matter with which the gases can combine. In both of these engineering works an artificial coating of lime was formed in the interior of the boilers, by feeding regularly into them each morning for some time a whitewash of Irish lime and water. This expedient was quite successful in checking the corrosive action, and as the lime soon hardened, under the influence of the heat, no trouble was experienced in preserving the coating. Pieces of limestone were also placed in the feed tank or cistern, but it is doubtful if they produced much effect. The carrying out of the application of lime in this way, was due to the ingenuity of Mr. T. R. Horton. Where, however, it is possible to mix with Loch Katrine or other pure water, a proportion of a calcareous natural water for a time, the scale formed thus in working will probably be of a more enduring nature. I strongly recommend this plan to those using Loch Katrine water, who have access to former sources of supply.

2. Marine Boilers. We are introduced to a variety of corrosive actions in considering marine boilers, according as we have to deal with boilers working with nothing but fresh water or those which use a proportion of sea water. It is necessary, however, clearly to distinguish these two classes.

The only marine boilers as yet using exclusively fresh water in regular working with which I am acquainted are those of Rowan & Horton's, mentioned in the letter to *Engineering*, to which I have referred, and elsewhere, and those working on Perkins' plan. Some of the ordinary boilers used in steamers with what are called compound engines, have been occasionally wrought entirely with fresh water, but in every such case recorded, that manner of working was abandoned after a very short trial, in consequence of the rapid corrosion which was discovered to be going on. Boilers in vessels whose voyages are always made in sea water, are constantly liable to receive a small quantity of salt water by leakage through surface condenser joints, or some other connections, so that even where it is or has been the intention to use fresh water only, it is not possible without analysis to determine if that has been done. The first of the examples quoted above have, however, this element of uncertainty removed from their case in consequence of their steamers running in fresh water, except for a very small part of their voyage. In their case corrosion from fat acids and from galvanic action, of what may be called an intermittent kind, was experienced and successfully counteracted. These actions, and the respective remedies which were adopted, I have mentioned in the published letter referred to, and I quote them here because they show what are the corrosive forces to which marine boilers, working exclusively with fresh water, may be subjected. Lime was present in small quantity in the river water used to fill up the boilers at starting and to make up waste in working, so that the decomposition of fats already described could take place. When the grease was removed as much as possible by filtering the feed water, and the presence of any free acid neutralised by zinc the corrosion ceased. The galvanic action was also arrested by means of the filter, because in general this action is caused by local contact with particles of metal carried into the boiler, and not, as has been erroneously supposed, by means of the surface condenser and the boiler forming together the two elements of a huge battery, the steam and water being the exciting medium.

Of Perkins' boilers worked in steamers, we have no published accounts with which I am acquainted, so that we cannot say whether they have suffered from corrosion in the course of the exigencies of practical voyage making. It is, I know, the aim of Mr. Perkins to exclude if possible all sea water, and all oily matter from his boilers, and if successful in doing this, and working only with fresh water, the corrosion will not be great. Still there will be some, as the gases of the natural fresh water with which the boilers are filled at starting will oxidise their proportion of iron, and in the feed water, which, as condensed steam has been returned from engines through the surface condenser and discharged by the air pump into the hot well, there is of necessity (probably not much), yet some air present, as the condensation takes place in contact with air; and this air will also do its own share in corroding fresh portions of the clean surface of the boilers. It is probable that if these boilers are introduced into merchant steamers and become subject to the invariable emergencies of regular trading by which leakages, deficient supply, and contamination of feed water are experienced, and foreign substances find their way into the boilers, the evils of corrosion may be known to a greater extent than that to which they reach, where it is possible to observe all the precautions of the inventor of that system.

Generating steam from fresh water alone is undoubtedly the proper, as it is sure on this account to be ultimately the general, mode of operation with steam boilers, but for ordinary sea-going purposes, appliances must not be too delicate, but require to possess the power to endure abnormal and adverse conditions.

The case of a coasting steamer using in her boilers natural fresh water from two sources (one at each end of her voyage) whose boilers were destroyed by corrosion with great rapidity was made known by Mr. James Gilchrist, in a paper read before the graduate section of the Inst. of Engineers in Scotland, and published in February of this year in a periodical called *Marine Engineering News*. Analysis of one of these waters (the other having been Loch Katrine), and of the deposit found in the boilers are given in the paper with the opinions of two professional chemists, who ascribed the corrosive action to the injudicious use of a large quantity of tallow in engines and boilers. There is no doubt that the decomposition of the tallow was in itself sufficient to cause serious damage to the boilers in presence of fresh water containing a small quantity of lime; but the action in this case was modified by a fact not noticed by the chemists—viz., that during the voyage of the steamer all deficiency in feed water was made up from the sea. The boiler deposit consequently contains 9.11 % of magnesia, and 12 % of common salt, as well as 8.86 % of oil and organic matter; and it is to the presence and decomposition of chloride of magnesium to which the presence of magnesia in the deposit bears witness, as well as to the carbonic acid of the original boiler supply, that a great part, and probably the rapidity of the corrosive action, is, I believe, to be attributed.

This leads to the consideration of marine boilers using partly fresh and partly salt water, by far the most extensive class at present, and that which has suffered most from corrosive action.

A very intelligent account of the state of matters in this class of boilers is given by Mr. Milln, in a paper read before the Cleveland Iron Trade Foremen's Association, Nov., 1875, and published widely in the engineering periodicals. This author describes graphically the introduction of the surface condenser into marine engine practice, with which is coincident the commencement of all real trouble from corrosion, and he then describes the course of events with two distinct sets of marine boilers. In the first of these we have a good example of boilers which had been worked at comparatively low pressure, viz., twenty-five pounds per square inch and fed for four years with sea water—working during that time in connection with an ordinary injection condenser attached to engines which indicated 900 horse power. As the voyage was not of long duration and time was given for regular "scaling" of the boiler surfaces (i.e. removing the scale from them) at the close of every voyage, no damage was done by incrustation and no inconvenience beyond the cost of fuel consumed was experienced. The injection condenser was then replaced by a surface condenser, some of the old incrustation being left adhering to the boiler surfaces, and the boilers were worked for some time thereafter with fresh water, the deficiency in feed supply being made up from the sea. The crust was soon removed and the boilers corroded, showing pits and blotches and all the usual symptoms.

The other instance quoted by Mr. Milln is that of a new set of boilers working at sixty-five pounds pressure in connection with compound engines of 1700 horse power and surface condenser, evidently an excellent example of average modern steamship machinery. These boilers were worked from the first with fresh water, the waste being supplied by distilled water, yet the density of the water increased daily and corrosion proceeded at the same time most energetically. After one voyage the boilers were filled at starting with sea water, but no more sea water was added during the voyage except the small quantity necessary for surplus feed supply. Under these fresh circumstances corrosion still proceeded, though it was thought more slowly, and was only finally stopped by what is called "changing the water," i.e. blowing off a quantity regularly and replacing it with sea water, thus introducing fresh quantities of sea water into the boilers during the voyage.

This author then alludes to the many theories explanatory of corrosive action which have been started, but only to reject them all and adopt the popular error, that corrosion is due to a change supposed to be wrought upon the water itself by distillation or re-distillation, which according to some, confers upon it the properties of a powerful solvent of metals, and according to others, although they do not like to state it thus plainly, this distillation decomposes the water and dissociates its oxygen, which forthwith attacks the iron of the boilers, or as Mr. Milln puts it: "the constituent elements of water when frequently redistilled undergo such a change as to greatly intensify its action on or affinity for iron," One engineering journal indeed very confidently affirms that it is "a fact but too familiar to engineers that the continuous boiling of distilled water in an iron vessel causes the destruction of that vessel," but has to admit that the circumstance that that water also passes over a very great surface of brass or copper, (of the destruction of which, however, not a word is said,) complicates the aspect of the phenomena.

It must, however, be confessed by engineers, that of the data or investigations by which so apparently wild a theory has been established as a fact they are as yet profoundly ignorant, and as Mr. Milln observes "it is with regard to the nature of this change that we so much want information!" There is this solitary fact known and harped upon, viz.: that dry steam in contact for a period of time with iron or carbon in a tolerably fine state of division and at a red heat is decomposed hydrogen gas escaping, while the oxygen combines with the iron or carbon. But this has never been attempted with water nor can be done with steam below red heat. What is known of the action of distilled water proves, indeed, the clean contrary to this theory, and in illustration of "what is known," I refer to those investigations which I have already quoted. They prove that it is the presence of air or gases which makes the difference in the action of various pure waters, and even in that of the various salts dissolved in impure waters, and that when water is distilled free from air, its corroding power is lost. Thus the remedy for corrosion proposed by some engineers to-day—viz., that the condensed steam should be aerated, proves to be a foolish suggestion, for this would but *increase* the power of that water to corrode the iron of the boilers.

I shall be within the strict truth when

I say that it is hasty to conclude, from examples of boiler corrosion, that distilled water has to do with the corrosion, for the fact is that there is no case known in which the proper effects due to the employment of distilled water alone, and free from gases, upon the metal of boilers, could have been observed. The boilers of Rowan & Horton, and of Perkins, present the nearest approach to the conditions requisite for such information, but not all the necessary conditions are found even in these instances. The examples just quoted from Mr. Milln's paper are of the kind with which engineers are more generally familiar, and they do not give such data as would lead to the conclusions about distilled water. The opinion is therefore due to a hasty conclusion, drawn from the coincident occurrence of corrosion with the introduction of surface condensers.

In the first example, genuine distilled water was never present. The boilers were filled up with fresh water at starting with the surface condensers, but not only was waste and deficiency of feed made up from the sea during the voyages, but there was also the saline crust adhering to the boilers to be dissolved or partially dissolved by the fresh water. Contrary to the opinion of Mr. Milln and others, I maintain that just because analysis shows that such crust contains chloride of sodium (in appreciable quantity when formed at such a pressure as that of the boiler mentioned—viz., 25 lbs. per square inch), if not also other soluble ingredients, a certain part of the crust must have been—and in such cases always is—dissolved; and thus the crust is partially disintegrated, and the insoluble magnesia and sulphate of lime fall in flakes to the bottom of the boiler. The fact that the water did not long remain fresh does not in any way interfere with this opinion, for it is a fact well known that salts dissolve more readily in a solution of other salts than in fresh water. Hence the scale would come off even more rapid when a small quantity of sea water was used.

The second example started with boilers filled with natural fresh water, which itself has (as we have seen), if pure, power to corrode by its gases in solution; but although distilled and not sea water in this case was used for surplus feed supply, the salinometer test showed plainly that pure distilled water was never present, and that either sea water was getting in through a leaky condenser, or that fatty and other matters were accumulating in the boiler, the color and taste of the water being decided indications that such (and probably *both* of these) results were happening. After the first voyage which gave such results, sea water was regularly used in greater or less proportion.

Thus we must search for the corroding agents apart from the distilled water. The analyses by Dr. Wallace and others, of boiler crusts, and the researches of Wagner and Fischer quoted herein, reveal one very important one—viz., the chlorine or hydrochloric acid set free by decomposition of the chloride of magnesium in the sea water. This decomposition may take place under the influence of high temperature alone, when magnesium hydrate is deposited, while the iron is attacked by the hydrochloric acid, first cloride and subsequently oxide being formed. As the combined influences of temperature and carbonate of lime are present, it is probable that the sulphate of magnesia is also decomposed, and that some oxychloride of magnesia is also formed, but this has not yet been demonstrated by analysis of deposits, though it is the opinion of Dr. Mills and others that part of the magnesia reported in ordinary analysis of boiler deposit from sea water exists in that form. Dr. Fischer also demonstrates that this mutual decomposition of magnesium sulphate with calcium carbonate is a fact, and that the liberation of carbonic acid also necessarily takes place.

The researches of J. Y. Buchanan "on the power of sea water to absorb carbonic acid," to which I have already referred, have shown us that sea water, on account of the sulphates which it holds in solution, absorbs a large amount of that gas, which it readily gives up on the sulphates being decomposed or separated from the water. Such decomposition and precipitation of sulphates occur in marine boilers, besides there being, now since the surface condenser era, repeated boiling of the water, which of itself in time liberates nearly all the carbonic acid. We have in these two agents, viz—the hydrochloric acid of the decomposed chlorides and the carbonic acid, combined with high temperature and pressure, quite enough to account for most of the corrosion which occurs.

The researches of Stingl, which I have quoted, show the power for evil which greasy matters wield, and this specially I believe where the water is comparatively fresh, though not there alone. And where grease is allowed to reach the boilers it can also carry along with it particles of other metals, which, in spite of the incredulity of some engineers, have been found to do mischief, and are capable of doing, if possible, more in presence of salt water than with fresh, unless it be acidulated. It is not supposed that they can do *all* the mischief, or even any in places to which they cannot reach; it is sufficient that they are capable of doing some, and there are specimens extant (among the specimens collected by the Admiralty committee on boilers, for instance) of corrosion and abrasion of brass tubes and other parts of engines, which show that this is a real and not a fancied danger.

The simple explanation of the fact that all such corroding agents have done damage principally since the introduction of the surface condenser, is that the surface condenser, by separating the condensed steam from the sea water used to condense it, and by returning so much fresh water to the boilers, has reduced the proportion of sea water used in them below that point at which it is possible to form a protecting scale or crust by the saturation of a considerable quantity of sea-water. It also, as I have said, provides for the complete liberation, by repeated boiling, of the carbonic acid held by the sea-water.

That sea-water alone at the boiling point corrodes iron is proved by one of Wagner's experiments, in which the percentage of loss from a piece of iron plate which was kept in contact with boiling sea water and air for six weeks, steadily increased from 0.43% after one week to 1.24% after six weeks. And proof that in marine boilers a small proportion of sea water is capable of doing mischief while a large quantity is not, is found readily in the fact that engineers have repeatedly *arrested corrosive action* by simply increasing the quantity of sea-water in the boilers, but without altering any of the other conditions of working. It is always in boilers that are "worked fresh" (*i.e.*, with the minimum of sea-water) that corrosion proceeds most rapidly, and I know of one steamer (the S.S. Vespasian) where by continually working fresh, a new set of boiler tubes was required in little more than twelve months after starting, while after that time, in the same boilers, the use of a large proportion of sea-water was enough without further change in working to preserve the boilers from rapid corrosion. As soon as the smallest quantity of scale begins to form, destructive action is arrested. This is true of all the various kinds of destructive action, and explains how under the old regime none of these were known. It also shows how fallacious must be any conclusions drawn from comparisions of results with old boilers in any attempt to argue from them to results in modern ones, as though both were obtained under like conditions. Another proof of the existence of such decompositions as I have described is found in the fact that the water of boilers in which corrosion is going on becomes alkaline. This shows an accumulation in solution of the effect of the alkaline ingredients of the sea-water, by decomposition and the neutralisation of the acid ingredients, and it is for this reason that some have been disappointed by testing the water, who had concluded that if corrosion was due to the presence of acid substances then the water must be acid.

The pitting and blotching effects produced on the metal of the boilers prove on examination to be not so mysterious as our first apprehensions rendered them. The same results follow the use of corroding liquids in any metal vessels when exposed to air and to light. Even basins made of platinum, which is harder and closer in texture than any other metal, I am informed are found by chemists to wear in a similar way by having certain liquids boiled in them, and thus the effects are apparently due to non-homogeneity of the metals as well as to purity in some cases. Heat in most instances has a considerable share in directing the action which is usually found to have been more intense in the hotter regions.

Before adverting to a remedy for this action, I may say that in the boilers of the S.S. Propontis, analyses of crusts from which are given previously, the various results of corrosion were experienced. Increase of density in the water observed when nominally working with fresh water alone, proves from the analysis of the deposite then taken from the boilers, and from an estimation of the total solids in the water at the close of that voyage (made by Mr. Tookey, and found to amount to 3272.5 grains in the gallon), to have been due to leakage of sea-water into the boilers by means of connections with a small boiler used for supplying steam to a cylinder steam-jacket. Milkiness and acrid taste in the water were no doubt due to the presence of fatty substances in solution, as a large quantity of grease was collected on the filter through which all the feed water passed. It is probable that these two causes will be found to account in nearly all cases for the increase of density often observed in similar circumstances of working.

It now remains to suggest a remedy. Much has been said in favor of the use of zinc in boilers, but zinc will not do where any proportion of sea-water is used, because it is very rapidly decomposed by the salts in sea-water, and chloride of zinc merely adds to the impurities and evils of the case. It has been, and may be, used successfully in fresh water, where there is free acid to be neutralized, but there its usefulness stops as far as corrosion is concerned.

Filtering the feed water is a most excellent precaution, and should undoubtedly be universally adopted in order to prevent, as far as possible, the entrance of foreign substances into the boilers.

To prevent the corrosive action in them of matters in solution, which no filter can arrest, I believe no better remedy can be found than the forming on the interior surfaces an artificial coating composed of calcium sulphate and magnesium hydrate in proportions varying according to the pressure carried in the boiler. This can be readily fed in, in the form of a thin whitewash with fresh water, and should be applied to all boilers on the very first occasions of getting up steam in them. Otherwise corrosive actions may commence, and unfit the surfaces for the adherence of such a protecting crust. A protecting crust has repeatedly been formed in boilers by using salt water; and in one of Mr. Milln's examples he was able to keep this of proper thinness by regularly blowing off about 1.9th of the water evaporated. Yet this is, as he admits, a very troublesome, and not a safe method of working, and yet to keep such a scale on, it must be carefully carried out without intermission, because as soon as the boilers are allowed to "work fresh" that scale dissolves off. By making an artificial scale with fresh water, as suggested, its thickness is quite under control, and when once hardened by heat, fresh water will not dissolve it, and thus steam can be generated in the best way. Even if a small quantity of sea-water should leak in it is not likely that the coating would be injured.

Apart from such a plan there seems to be no hope of escaping corrosion and advancing at the same time in engineering practice, until it is possible to have copper boilers. And yet, even then, as the recent experiments of Carnelley on "The action of water and of various saline solutions on copper," seem to show, we should still have to combat the same difficulties.

FORCE.

By DE VOLSON WOOD, M. A., C. E.

Written for Van Nostrand's Engineering Magazine.

I had nearly completed an article upon this subject when I received the November number of the Magazine, in which is an abstract of a lecture by Professor Tait, upon the same subject. That article covers nearly the same ground as the one I had prepared, and many of the views presented are identically the same; still there are a few points to which I wish to call attention, and more particularly to the elementary idea of the measure of force.

It is conceded that technical terms should be as definite and limited as possible. They should not be ambiguous, though when used in different branches of science, the same word may represent different ideas. The common term *power* is used in Mechanics, Optics, Psychology, &c., and in each, it has its peculiar meaning. But in the same science the same term should not be applied to two distinct ideas. Force, in Mechanics, is defined to be "That which moves, or tends to move a body, or to change its rate of motion." That which tends to move a body without actually producing motion, is called *pressure.* Is pressure force? Can we properly distinguish between that agent which only tends to produce motion and that which actually produces it? Is the agent which produces motion equivalent to a pressure, or is it distinct from it? I wish to show that pressure, whether it produces motion or not is a physical manifestation of force, and that the forces of nature, such as attraction and repulsion, when they do not produce pressure are equivalent to a pressure and may be measured by the same units.

The general reader may at first suppose that I am raising an imaginary question, since the assumed distinction is not even suggested by the definition. But such is not the case, for certain English writers have clearly made the distinction. For instance, a few years since, during the discussion of a question before the "Institution of Engineers," one speaker remarked that much of the difficulty connected with the case arose from the fact that many writers made no distinction between *force* and *pressure*; that a force was that only which produced motion, and that pressure does not produce motion. Again, Price, an English author, in the introduction to the third volume of his "Infinitesimal Calculus," gives the usual definition of force, but in his introduction to Dynamics, he at least intimates that force is that which produces motion. Also Professor Tait, in the lecture referred to, defines a unit of force to be that which "In one second, gives to one pound of matter a velocity of one foot per second." This definition may be extended so as to be the measure of a *pressure*, by defining it to be that which would produce a velocity of one foot per second when acting upon a pound of matter perfectly free to move. Many other writers define the unit in the same way.

I will show hereafter that this is a correct unit, especially if the force be constant, but it is neither the simplest nor best. As we do not presume to know anything of the essential nature of *force*, it must be measured by its effects. A horse draws a cart and exerts a force which may be measured by pounds. A locomotive pulls or pushes a train of cars, and by placing a dynamometer between it and the train, the pounds of force which it exerts at any instant may be measured whether it moves the train or not. Similarly, whenever any effort is exerted, as a push through a rod or bar, or as a pull through a chain, rope, or rod, the effort can be measured by pounds. The force of gravity exerted upon a body at rest equals the weight of the body and is measured by pounds, but when the body is in motion, is the *force* still equal to the weight? To show that it is, we make use of the well-known formula,

$$F = Mf$$

in which

F = the value of a single force (measured in pounds) acting upon a body perfectly free to move.

M = the mass of the body moved, and

f = the acceleration produced by the force F.

The value of M equals $W \div g$, where W is the weight of the body whose mass is M, and g the acceleration due to gravity at the place where W is determined. Hence, the formula becomes

$$F = W\frac{f}{g}$$

If we conceive a body whose weight is W to be pushed or pulled by a constant force equal to its weight, that is, by a force equal to W, we have

$$W = W\frac{f}{g};$$

or

$$f = g;$$

hence, the acceleration will equal that due to a body falling freely by the force of gravity.

To illustrate further, suppose that a body is placed upon a horizontal plane and is free to move without resistances, such as friction, adhesion or resistance of the air, and if the body be drawn by a string of which the constant tension equals the weight of the body, then will the motion horizontally be precisely the same as if the body fell vertically by the force of gravity. It is easy to hold the body so that when the tension of the string is the same as before, there will be no motion; but the effort in both cases will be the same, and this effort is measured directly by the tension of the string, which we know may be expressed by a certain number of *pounds*. I do not think it advisable to consider anything as force, or as the measure of force which cannot itself be measured by this unit. Momentum MV is measured by *foot-pounds*, and hence *generally* is not a measure of force. I say *generally*, for I will hereafter show that under *certain restrictions* it may be used as the measure of force. Similarly, work, living force, and energy, are measured by *foot-pounds*, and are not *generally* the proper measures of force.

Force manifests itself in a variety of ways. That which draws bodies towards each other, or repels them from each other, or holds the particles together forming solids, or which forces particles from each other, tending to disperse them, or which causes a particular arrangement of the particles as in fibrous and crystaline bodies, is force, whether it be called attraction, repulsion, cohesion, adhesion, polarity, electrical phenomenon, or chemical action.

A recent writer in Nature, reviewing a report of Professor Tait's lecture, says: "The whole controversy on the word force is as to the *method of measuring* a pressure or tension." Here *force* and *pressure* are considered the same. The natural mode of measuring *pressure* or *tension* is by pounds. He proceeds to say; "If we regard the time of action, the *effect* is represented by the momentum; and if the space through which exertion is made, the *effect* is represented by the work." These remarks are correct, but it should be observed that the *effects* are final effects; that is the momentum MV is the result of an effort for a time t, where t may be any finite time; and similarly in regard to work. He continues: "Either of these would measure 'force,' and there would be no inaccuracy if careful explanation were given as to the method used and the sense of the words." A simple illustration will show that neither of these can be a *general* measure of force. Suppose that a force of constant uniform intensity, produces a momentum of MV in a time t. Another force, beginning with less intensity, but gradually increasing with the time, might in the same time produce the same momentum. Certainly the momentum in the latter case, if a measure of the force at any instant of the action, will not be a measure of it at any other instant. Or the force may act very irregularly, and yet at the end of the time t, produce the same momentum. What in this case will be the measure of the force at any instant?

There is just one case in which momentum might be used to measure forces, and that is when the forces have a constant intensity during action. Such are called constant forces. Some writers have considered the formulas which are especially applicable to this case, as of a *general* character. For this case we have

$$F\,t = M\,V.^*$$

Similarly for another force, acting during the same time, we have

$$F_1\,t = M_1\,V_1$$

Hence,

$$F : F_1 :: M\,V : M_1\,V_1$$

And by assuming one of the forces as a standard, or unit, for measuring all other forces, we have

$$F_1 = \text{UNITY} = M_1\,V_1$$
$$\therefore\ \ F = M\,V.$$

But forces generally are not constant, and to find a general expression for the pressure which moves a body in terms of the movement, we resort to the language of the Calculus. We consider that the force is measured by the momentum which it would produce in a unit of time, if it acted with the intensity that it had at the instant considered. The increased or decreased velocity which would be produced, is called *acceleration*,

* The general expression for any *law* of force is,

$$\int_0^t F\,t = M\,(V - V_0)$$

and hence the measure of the intensity of a variable force at any instant of its action when moving a perfectly free mass M, is the product of the mass by the acceleration, or, as we have previously expressed it,

$$F = Mf.$$

This is a well-known expression, accepted by all writers upon Mechanics, and a careful study of it will remove much of the difficulty which seems to be involved in the case.

It will be observed here that F means a certain number of pounds, or their equivalent, and the right hand member may be reduced to the same thing. For we have

$$F = \frac{f}{g} W;$$

in which $\frac{f}{g}$ is the ratio of two accelerations, and hence, is an abstract number, by which, if W be multiplied, the result will be a certain number of pounds.

If in the expression

$$F = Mf$$

we make M and f each unity, and consider F as constant, we have

1 lb. of force = 1 lb. of mass × 1 foot velocity;

the second member of which is the *unit*, proposed by the English writers for measuring force. But we see from the preceding principles that to be a *general* measure, the *unit* should be *that which would produce an acceleration of one foot per second in one pound of mass free to move.*

The second member of the equation is, as we have seen, an equivalent for the first member. It is only applicable to moving bodies, while the first member is general, being the direct measure of the pressure or tension, whether the body upon which the effect is made moves or remains at rest, and hence, we think, is the more natural, and certainly the more general measure of "force."

IRON AND STEEL THE FIRST THREE QUARTERS OF 1876.

From the London "Mining Journal."

In a recent number of the *London Mining Journal* was published the Custom House Returns of the commerce which took place for the first three quarters of this year in the three superior metals—tin, copper, and lead, assigning as our reason the importance of marking at each quarter of the year the progress made in the metal trade, in order that the present condition and prospects of mining may be more precisely ascertained, in the interest of that great branch of British industry of which the *Mining Journal* is the oldest and most efficient chronicle. Indeed, to do this is a necessity, for it is impossible to measure aright our mining prospects without watching with sustained vigilance the progress of the commerce in the products of our mines. An intelligent observer, if not thoroughly acquainted with the ways of mining brokers and agents, would be puzzled if he were to spend any day a few hours on the mining share-market, or call at the offices of Stock Exchange and mining brokers, and listen to their very various and even contradictory accounts of the "situation." We were informed this week by a gentleman largely interested in Welsh lead mines that business is reviving, that there is a rapidly increasing demand for shares in lead mines, more particularly Welsh. Another gentleman assured us that the stir in business proceeded from the success of the lead mines of the North of England. A third gentleman, an intelligent broker concerned in Welsh lead mines, assured us with doleful countenance that "there is no business doing; nothing whatever." Another said he "never knew things worse." His department is more especially in copper. A Cornish gentleman of forty years standing in mining experience declared that "tin mining in Cornwall was on the point of extinction," while another gentleman, who had equal opportunities of knowing, said, "Tin will look up, we need not now be much afraid of foreign competition, and the prospects of lead mining are excellent." In fact, each man refers to the quality of his own individual business as the only test of the state and the prospects of mining in general. But when we give the statistics of the trade in metals and minerals at least every quarter, as furnished by authority, that "regulates the clock," and tells us what the real time is. This has been done for the third quarter and the three quarters of the year in connection with the three valuable metals above named. Our space did not permit us to comprehend all; let us now endeavor to point out the statistics of the iron trade as we have collected and collated them.

Although Great Britain is a great exporter of iron, and has been greater, our imports are also considerable, chiefly of Swedish iron for the manufacture of steel, the ores of that country being better adapted to the purpose than any other. Eventually this trade will be greatly lessened, some think abolished, because our new processes for the manufacture of steel enable us to adopt our own ores, but for some time to come iron is likely to give place to steel for various uses, more particularly rails, that the imports are not likely to diminish. During the last nine months ores were imported to the value of £681,000 (we shall confine ourselves to round numbers, giving the nearest round number approached). There has been a great increase over the first three quarters of 1875, when the value was £485,000 but the more active year, 1874, shows within the same period a value of £876,000. But last month shows that more iron was wanted (chiefly for making steel) than in the corresponding month of the two previous years; the figures were (moving backward), £87,642, £68,000, £77,000. Bar-iron was imported during this year up to the 7th of this month to the value of £750,000 against £950,000 last year in the same time, and £727,000 the year before that. It appears that foreign makers are not supplying us with bar-iron to the extent of last year, but the same activity in these imports prevailed as in those of ores; last month the value being more than in 1875 or 1874, and in proportion to the whole nine months increased about thirty-seven per cent.

Heavy complaints have been made that the German, Belgian, and even French, are beating us in iron manufactures in our own market. There are certainly some departments of iron manufactures in which the Germans excel us, both in skill and taste; but the area of coal is too small in Belgium for that country to maintain a permanent competition with us in any department of iron-making. The value of manufactured iron imported this year has been £1,047,463—£30,000 less than last year, but over £70,000 more than at the same time the year before that. There is no material difference in those figures, but for the month there has been a marked diminution; the value for September was £111,145, against £155,000 in that month twelvemonths, and £149,000 in September two years. The value of imports for the month sustained the proportion of the nine months. As to quantity, the number of tons of ore greatly increased, and of bars twenty-five per cent., and there was over 160,000 cwts. more of manufactured iron imported. The imports of iron have been manifestly cheaper, an element, of course, to be considered in any estimate as to foreign competition. Our steel imports were all unwrought. For the nine months they were valued at £112,000, nearly thirty per cent. more than during the corresponding period last year, which was only a trifle less than in that period in 1874. But the month shows a signal falling off, the value having been only £9000. It was 250 per cent. more in September, 1875, and four times as much as in that month, 1874; and for the reasons given the diminution will, after some time, be more determined. The increase in quantities for the nine months shows falling prices upon the Continent; it was 7400 tons as compared with 5200 tons within the same time last year, and 4466 tons in that of 1874.

Perhaps it is proper here to notice our imports of pyrites. Those of iron, copper, and sulphur cannot be separated in the returns. The value of them all in the last three-quarters of a year has been very considerable, and ought not to be overlooked, as they constantly are in statistics of the metal trade. The amount has been £1,021,000 over £100,000 less than in the first three-quarters of last year, and a few thousand pounds less than in those of the previous year. The decline on the month has been large, whether as compared with the whole nine months of this year or the corresponding months of previous years. There have been no material alterations in quantities, into the detail of which it is not necessary to enter. It must not be supposed by any reader who has not paid particular attention to the course of the metal trade that all the iron we import comes into direct competition with our own productions. Considerable quantities are exported, furnishing the metal or general merchant with a profit. Of course, there is no "re-export," as it is called, of ores; they are cumbersome cargoes, and not of an intrinsic value to sustain a commerce in them; besides, we only import what we require for manufacturing purposes. Neither do we reship pyrites of any kind. But of the bar-iron which we received we exported a value of £290,000. Last year it was £357,000, and the previous year rather less than this. The falling off in the "re-export" of iron does not appear to be due to any other causes than the general decline of trade here and elsewhere. Of iron manufactures other than bars imported we do not appear to have sold a single ounce. The whole came into competition with our own market when it made its way by superior artistic design and finish.

Of the unwrought steel bought here £37,000 worth was sent away again, an increase of £4000 upon the first three quarters of last year, and £3000 more than twice as much, in the corresponding months of 1874. For the month we exported nearly double the value of imported steel, as compared with the same time last year. Of the export of British iron and steel production we have little, if indeed anything, to say which would cheer the gloom which hangs over this department of our mining industry and commerce in metals. The falling off has been signal and terrible, and any light that hope sheds upon our path is rather in the prospect of renewed railway demand, and the certain change from iron rails to steel in every country. This will undoubtedly cause a renewed activity. Our great metallurgists and manufacturers are also beginning to take measures for raising the standard of art-workmen in iron and steel, so as more effectually to compete with our continental rivals, whether German, Belgian, or French. The value of our exports of iron and steel for the past three quarters of this year has been £15,690,000, nearly 4½ millions less than in the corresponding three quarters of last year, and more than eight millions less than in the corresponding quarters of 1874.

Some hopes have been expressed lately in the columns of this Journal, and in the Press of the North of England and South Wales, that the export trade is improving a little; we are no croakers; but sad to say we see no decided sign of this. The value of the last month's exports was higher in proportion to the whole nine months. Were the whole three-quarters as good as the month the results would have been more favorable to the extent of about £2,000,000, for the exports of September were valued at £1,934,000. That, however, was less by £300,000 than September, 1875, and less by close upon £750,000 than in September, 1874. The decline has been very general, pervading nearly all branches. Unwrought steel fell from £838,800 in the longer period to £673,000; manufacturers of steel, or steel and iron combined from £615,000 to £575,000; pig-iron from £2,641,000 to £2,115,000; bar, angle, bolt, and rod from £2,048,000, to £1,459,000. In railroad iron of all sorts the decline has been very heavy. Last year in the first three-quarters the value was £4,500,000, this year not far from £1,750,000 less. For hoops, sheets, boiler, and armor-plates the fall was about £400,000, from £2,464,000 last year. Tin-plates declined still more, showing a diminution of £750,000 upon a value of less than £3,000,000 last year. Cast or wrought iron, and all other manufacture except ordnance, showed a recession from £3,368,000 to a trifle over £3,000,000. The only gain was in old iron exports for re-manufacture elsewhere, too small for notice.

It is well understood that iron enters largely into the composition of machinery. The value of steam-engines exported was over £2,000,000 the first three quarters of last year; this year, so far, only £1,470,000. The decline in other descriptions of machinery was even more serious; from less than £5,000,000 there was a decline of nearly £900,000. Hardware and cutlery also presented a retrogression. Last year in the first three quarters the value was £3,200,000; this year, £2,650,000. In arms and ammunition the decline was not very heavy, but both years show a great falling off from the year before. The depression in the month of September is represented by the following figures—£2,667,000 in September, 1874; £2,236,000 in September, 1875; and £1,935,000 in September, 1876.

Unhappily the decline in quantities has been extraordinary as well as in values. Yet the cloud seems a little breaking up, and some streaks of light are breaking through. British energy, capital, perseverance, and trust in Providence must accomplish the rest.

THE PHOSPHATE SEWAGE COMPANY'S PROCESS.

By W. KEITH.

From "Journal of the Society of Arts."

The Phosphate Sewage Process is based upon the use of specially prepared phosphates of alumina and lime with sewage. The action of the prepared phosphates upon the sewage may be familiarly described as a curdling or coagulation of the fæcal matter in the sewage, giving it thereby a greater tendency to separate itself from the general bulk of water with which it has been intermixed. The next step is the use of lime, and this draws from the sewage the soluble phosphates which have been added in the process, forming therewith what is known as precipitated phosphate. The formation of this precipitated phosphate not only has the effect of recovering from the sewage water the soluble phosphate it contained, but it also carries down with it the curdled or coagulated fæcal matter. The sewage having been thus prepared, a separation of the solid matter is readily accomplished by means of "precipitating tanks," constructed so as not to interfere with that quiet condition of the water which is necessary for the deposit of a light and flocculent precipitate.

By these successive steps the deodorization and defæcation of the sewage are accomplished, so that, whilst a flow of sewage enters at one end of the works, a stream of clear, bright effluent passes away at the other, leaving in the precipitating tanks a deposit of the solid matter which has been separated from the sewage. This solid matter is discharged into shallow beds, where it is allowed to dry, and it is either moulded into bricks and dried in the air, or simply turned over and the drying completed without further trouble, which is undoubtedly the cheapest course of procedure.

Manure obtained under the phosphate sewage process has many and great advantages over the ordinary sewage manures, which, from their inferior quality, are difficult of sale. As a matter of fact it has been found more economical to purify the sewage by the use of a better and more expensive class of material, which, when it has accomplished the duty of purifying the sewage, adds to the utility and market value of the manure made. The manure produced under this process enables it to be compared favorably with other manures. The average composition of the manure made from London sewage is about two and a half per cent. ammoniacal matter and twenty-two per cent. precipitated phosphates, and, consequently, it is a really valuable manure.

The sewage of Hertford is one of that class which offers especial difficulties, consequent upon its having to be discharged into the Lea, which is largely drawn upon as a water supply, and is for this reason very jealously guarded. The sewage of this town has been continuously treated by this process for about eighteen months, and it has so far complied with the stringent conditions of producing a thoroughly good effluent water, that the Corporation have given an official certificate testifying to the satisfactory character of the effluent water discharged.

Professor Wrightson, in his report to the Cirencester Chamber of Agriculture upon one of the most complete series of field experiments of modern times, says of this manure :

"It is advertised at £4 per ton, delivered in railway trucks, and I can speak most approvingly of the fine, dry condition in which it is sent out, in strong bags of 1 cwt. each. Last year I spoke of its uniform action over many of the farms upon which it was tried. It did not produce so great an increase as superphosphate, but then it was sold at a lower price. Reducing its effects to a money standard, I found last season that it produced its increase over unmanured plots, taking the average of the entire series, at 3s. 2½d. per ton, whereas superphosphate, valued at 6s. per cwt. produced its increase at 3s. per ton. The results of 1875 are certainly favorable to this sewage product, as may be readily seen by consulting the table showing the increase per acre of the fertilizers used over the average unmanured plots. It rivals superphosphate in several cases, especially at Stratton, where it gave a distinctly better result. In other cases the popular manure, superphosphate, is run very hard by it. Twelve shillings per acre is some vantage ground when compared with the 18s. per acre at which I have valued the superphosphate, and, applying the rule for finding the profit from any fertilizer, I find strong evidence, now extending over two seasons, of the usefulness of this substance."

PRESERVATION OF TIMBER WITH SALTS OF COPPER.*

By M. ROTTIER.

From "Engineering."

1. Wood impregnated with copper will not last underground for an indefinite time. However carefully prepared it decays after a longer or shorter interval. This fact admits of ready explanation.

Under the influence of certain agencies wood so prepared gradually parts with the small quantity of copper fixed in its tissues, to the pressure of which its antiseptic powers were due. So long as the wood contains a certain proportion of copper, it resists decay ; when the copper is no longer there it is in pretty much the same condition as unprepared wood, and speedily decomposes. This is clearly shown by the following experiment :

Some thin slips of soft poplar-wood were carefully dried and afterwards impregnated with a solution of pure copper sulphate, containing 1.5 gramme of crystallized sulphate of copper per 100 parts of water. It was not found necessary to resort to pressure, as the wood being very thin, mere immersion sufficed for its thorough impregnation with the antiseptic fluid. The strips were washed several times in plenty of water, and dried. Some were then set apart for analysis, and others buried in a box filled with ordinary garden mould kept continually moist by repeated waterings. The annexed Table shows the results :

	Length of Time the Strips were interred.	Proportion of Crystallized Sulphate of Copper found in them.	Remarks.
	days.	grams.	
1 gramme of wood prepared & dried	0	0.00410	
1 gramme of wood prepared & dried	68	0.00250	Wood still perfectly sound.
1 gramme of wood prepared & dried	117	0.00220	Strips showing a few black spots.
1 gramme of wood prepared & dried	179	0.00170	Wood almost entirely decayed.

* Communicated to the Academie des Sciences de Belgique.

Here we see, as plainly as it can well be shown, that the preservation of the wood was due to the presence of the cupreous sulphate ; by degrees, as it parted with this metallic salt, it decayed. Now let us consider the causes of removal of the copper. They are three : 1. The presence of iron. 2. The presence of certain saline solutions. 3. The presence of carbonic acid.

To a Belgian engineer, M. Van der Sweep, belongs the credit of having first called attention, some years ago, to the action of metallic iron on timber prepared with salts of copper.

The researches of Kuhlmann, Themard, and Hervé-Mangon on this point, appear sufficiently conclusive to render further experiments unnecessary. But it was thought desirable to ascertain the point at which the presence of iron in cupreous solution becomes detrimental to the antiseptic properties of wood.

A certain number of thin slips of wood of the same size were prepared with solutions of copper sulphate containing different proportions of sulphate of iron, The length of time the wood remained sound in each case was noted. The annexed Table shows the results :

Number of Experiment.	Weight of Slips.	Composition of Solutions employed.			Slips completely destroyed at the end of :
		Cu So_4 5 H_2 O.	Fe So_4 7 H_2 O.	H_2O.	
	grams	grams.	grams.	grams.	days.
1	0.25	0.00	1.50	100.00	56
2	0.25	0.50	1.00	100.00	83
3	0.22	1.00	0.50	100.00	97
4	0.22	1.20	0.30	100.00	100
5	0.22	1.30	0.20	100.00	103
6	0.19	1.40	0.10	100.00	103
7	0.19	1.45	0 05	100.00	108
8	0.18	1.48	0.02	100.00	109
9	0.20	1.49	0.01	100.00	109
10	0.23	1.495	0.005	100.00	110
11	0.20	1.50	0.00	100.00	109
12	0.25	1.46	0.04	100.00	100
13	0.24	1.48	0.02	100.00	100
14	0.26	Strip not prepared.			34

In all these experiments, the wood was in every case entirely rotted, so that it could not be drawn out of the soil without crumbling. Very exact analysis was, therefore, impracticable, and but little importance should be attached to minute differences in the results. An examination of the last Table shows :

1st. That sulphate of iron has a certain antiseptic power, which is, however, much inferior to that of sulphate of copper.

2d. That samples of wood prepared with different solutions containing the sulphate of iron and copper together last about the same time, unless the sulphate of iron is present in very large quantity.

3d. That there is no reason to give the preference in wood-preserving to chemically pure copper sulphate over the ordinary sulphate of copper of commerce.

M. Boucherie has advanced a contrary opinion. He asserts that cupreous sulphate containing five or six per cent. of sulphate of iron should be rejected altogether, and that in wood-preserving only copper sulphate, which has been suitably purified, should be employed.

Without entering upon this question, it may be well to recall the experiments of Payem, on the wood of an ancient wheel found, some years ago, in the Sao Domingo copper mine in Portugal. This wheel was in a perfect state of preservation after having lain for fourteen centuries in water impregnated with the sulphate of copper and iron, and containing a notable proportion of the subsulphate of these metals.

Certain salts have an injurious action on wood impregnated with sulphur of copper. When wood so prepared, after washing in distilled water, is plunged in a solution of the chloride or carbonate of soda or of carbonate of potash, it will be found after the lapse of a certain time, that these solutions contain a notable percentage of copper. On the other hand, if preparation of copper in the wood be determined before and after an immersion of varying duration, it will be found to decrease steadily in proportion to the length of the immersion. This explains the failure of all attempts to protect timber against the action of sea-water with sulphate of copper. The salts in the sea-water enable it rapidly to dissolve out the copper from the woody fibre. So long as the copper is present in the timber, the latter is spared by the marine mollusca; when the greater portion of it is washed out, the wood speedily succumbs. This was proved by exposing a piece of beech-wood thus prepared to the action of sea-water for a given time. One part of the wood was untouched; the other was deeply eaten away by the borer. A sample of the wood weighing 2.5 grammes, from the untouched part was found to contain 0.01140 gramme of sulphate of copper; a sample of equal weight from the portion attacked contained 0.00015 gramme only. To a similar cause most likely is due the rapid decay of sleepers prepared with sulphate of copper, when laid in tunnels in certain soils, in those of a calcareous nature more especially. The water filtering through these soils very possibly becomes charged with certain salts (bi-carbonate of lime, &c.), which like sea-salt, carbonate of soda, and others, have the property of carrying off the copper from wood prepared therewith.

Solutions containing carbonic acid act in the same way. About three grammes weight of wood prepared with sulphate of copper, was carefully washed, and exposed for seven days to the action of frequently renewed solutions of carbonic acid (*i. e.* aërated water). Each time the water was removed it was tested for copper. The total amount of copper thus extracted in the seven days was 0.0028 gramme of sulphate. Under similar conditions pure water has no effect. Maxime Paulet, in his last work describes an experiment in point:

"Take," he says, "some wood sawdust impregnated with copper sulphate, and wash it repeatedly until the presence of copper in the latter can no longer be detected with ferrocyanide of potassium. Throw this sawdust, out of which all the copper has apparently been extracted, into ordinary aërated water, that is to say water highly charged with carbonic acid, and leave it there for awhile. The water is found to show traces of copper. How has this come to pass? We may be permitted to surmise that the oxide of copper has become dissolved under the influence of the carbonic acid and so extracted from the wood. The experiment requires to be repeated; but if the foregoing view should be confirmed, the practical importance of the deduction is sufficiently obvious."

Experiments were next made to ascertain whether *pure* water also exerts a solvent action on the cupreous combinations contained in wood prepared with copper sulphate.

1st. In an open vessel filled with distilled water were placed some slips of wood prepared with copper and carefully washed. The mouth of the vessel was covered with a pane of glass to prevent evaporation, and left exposed to the light for a considerable length of time. Portions of each strip, about one-fifth of the superficial area of each, were cut off before immersion to serve as standards. Similar test-pieces were cut off from the slips at the end of 7, 13, and 19 months' immersion.

	Grammes.
The average proportion of copper in 1 gramme of the prepared wood before immersion was.....	0.0073
The average proportion of copper in 1 gramme of the prepared wood after 7 months' immersion in distilled water...............	0.0054
The average proportion of copper in 1 gramme of the prepared wood after 13 months' immersion in distilled water...............	0.0060
The average proportion of copper in 1 gramme of the prepared wood after 19 months' immersion in distilled water...............	0.0054

The action of the water was thus clearly manifest; but then the question arises, was the solvent power exerted by the water itself, or by a small proportion of carbonic acid which may have been present therein? Too much stress must not be laid on the result of a single experiment; but the latter supposition would account for the close equality of the copper in the last three tests.

2. Distilled water was boiled in a glass receiver so as to expel the gas. Slips of prepared wood, similar to those used in the previous experiment, were immersed in the water, which was again boiled, and the neck of the receiver sealed with the blowpipe. After 200 days it was opened. This water contained 0.0002 gramme of copper.

Even in this case, however, it must not be too hastily concluded that the solvent action really was exerted by the water. Even after long boiling, water is wonderfully retentive of small quantities of carbonic acid. And, again, if the wood was not thoroughly and uniformly saturated with the copper, the smallest fragment that had escaped impregnation might have supplied a certain volume of carbonic acid to the water. In any case, the foregoing experiments prove that the action in such cases is extremely slow.

As timber prepared with copper is liable to decay when the proportion of the latter contained in it becomes very small, it appears probable that its duration might be prolonged by fixing a larger quantity of copper in the ligneous tissue. Let us now see whether experiment confirms this supposition.

The ordinary method of preparing timber does not permit of the solution of the question; wood plunged in a solution of copper sulphate takes up a pretty nearly constant quantity of the metal; and that quantity is very small. Special processes are requisite to introduce larger quantities of the metal into the tissues. The following have given satisfactory results.

1st. *Acetate of Copper.*—The tendency to fix themselves in ligneous fibre is displayed in different degrees by different copper salts. The acetate is specially noticeable in this respect. Slips of wood impregnated with acetate of copper were found to contain 0.0104 to 0.0170 gramme of copper per gramme of wood; whilst those prepared with equal weights of sulphate contained only 0.006 to 0.007 gramme of copper per gramme of wood.

2d. *Use of Organic Substances.*—Some organic substances act in respect of the salts of copper like mordants on dye-stuffs—they assist the absorption and fixation of the copper by the ligneous fibre. The two organic substances, which were found to give the most remarkable results, were indigo and catechu.

3d. *Heating of the Wood.*—When slips of wood prepared with a solution of copper (acetate or sulphate, &c), on their withdrawal from the bath, are exposed to a high temperature, they appear to assimilate and retain in an insoluble form, a somewhat larger proportion of copper than it would be possible to introduce in the ordinary way. The following Table gives the results of some experiments under this head :

	Temperature to which heated.	Copper in one Gramme of Wood.
	deg. C.	grms.
Strips of wood prepared with copper sulphate, and heated to....................	65	0.0075
Strips of wood prepared with copper sulphate, and heated to....................	100	0.0090
Strips of wood prepared with copper sulphate, and heated to....................	125	0.0114
Strips of wood prepared with acetate, and heated to...	100	0.0231
Strips of wood prepared with acetate, and heated to....	130	0.0240
Strips of wood prepared in the ordinary way.........	..	0.0073

a. Indigo.—A slip of wood was dyed blue with indigo, and then prepared with a solution of copper sulphate in the ordinary way. It was found to contain 0.0093 gramme of copper per gramme of wood, which is rather above the average of ordinary wood prepared in the same way. The experiment was repeated with indigo-dyed and white calicoes. The blue retained after washing 0.00409 gramme of copper per gramme of material, whilst the white contained 0.00195 gramme only. A blue calico with a white pattern was treated with copper sulphate in the same way, and the white portions cut out. The proportion of copper fixed by the latter was found 0.00026 gramme only; the blue ground fixed 0.0130 gramme per gramme of the stuff.

b. Catechu.—If a decoction of catechu be mixed with a solution of acetate or sulphate of copper, a liquor is obtained which allows of the fixation of a very considerable quantity of copper in wood. Strips of wood so prepared were found to contain 0.0145 gramme to 0.0460 gramme of copper per gramme of wood. Contrary to expectation, this method proves of little practical value. Catechu requires the presence of oxygen to produce the required effect. Thin strips of wood, having a surface large in proportion to their thickness, may thus be made to absorb considerable quantities of copper, but in timbers of any moderate scantling, the effect is merely superficial, and the proportion of copper fixed relatively small.

c. Ammoniacal Copper Salts.—The use of the ammoniated salts of copper allows of the introduction of large quantities of copper in woody tissue. Numerous experiments showed that wood so prepared contained from 0.0166 gramme to 0.0730 gramme of copper per gramme of wood.

It appears, therefore, that there are various ways of impregnating wood with copper in excess of the ordinary proportion. It remains to be seen whether the excess of copper gives a notable increase of durability. To decide this question seven strips of wood were buried in the ground side by side: 1. A strip unprepared, A. 2. A strip prepared with sulphate of copper, B. 3. A strip prepared with acetate, C. 4. A strip prepared with catechu, D. 5. A strip prepared with sulphate and afterwards heated, E. 6. A strip prepared with acetate and heated, F. 7. A strip prepared with cuprammonium sulphate. The results are given below:

(*See Table on following column.*)

	1 Gramme of Wood contained of $Cu\ So_4\ 5\ H_2\ O$.	Wood compl'tly rotted after.
	grammes.	days.
A. Unprepared wood.......	0.00002	30
B. Wood prepared with copper sulphate in the ordinary way............	0.00730	67
C. Wood prepared with acetate of copper........	0.01000	95
D. Wood prepared with sulphate of copper and catechu..............	0.01300	120
E. Wood prepared with sulphate of copper and heated afterwards....	0.01000	80
F. Wood prepared with acetate of copper and heated afterwards.........	0.02300	160
G. Wood prepared with ammoniacal copper sulphate................	0.01660	130

These results have been confirmed by repeated experiments, in some of which the prepared slips of wood were found as fresh and sound after an interment of 200 days, as when first consigned to the ground.

Of the several methods above described, one only, the employment of ammoniacal copper salts, appears of any practical utility. Acetate of copper and indigo are each of them too expensive; catechu is too restricted in its action. On the other hand, the ammoniated salts of copper are adapted for general use, and are, comparatively speaking, cheap, and the slightly increased outlay necessitated by their adoption would be more than compensated by the assurance of greater durability in the timber so prepared.

PROTECTION OF BUILDINGS FROM LIGHTNING.*

From "The Architect."

THE author stated that those who had given directions for the construction of lightning-conductors had paid great attention to the upper and lower extremities of the conductor. They recommended that the upper extremity of the conductor should extend somewhat above the highest part of the building to be protected; that it should terminate in a sharp point; and that the lower extremity should be carried as far as possible into the conducting strata of the ground, so as to "make" what telegraph engineers called a "good earth." The effect was to tap, or, as it were, to gather the charge by facilitating the discharge between the atmospheric accumulation and the earth. That would cause a greater number of discharges than would have otherwise occurred; but each of them would be smaller than those which would have occurred without a conductor. It appeared to him that these arrangements were calculated rather for the benefit of the surrounding country, and for the benefit of clouds laboring under an accumulation

* Abstract of Prof. Clerk Maxwell's paper before the British Association.

of electricity, than for the protection of the building on which the conductor was erected.

What the people really wished was to prevent the possibility of an electric discharge taking place within a certain region—say the inside of a gunpowder manufactory. If this were clearly laid down as the object to be aimed at, the method of securing it was equally clear. An electric discharge could not occur between two bodies unless the difference of their potentials was sufficiently great compared with the distance between them. If, therefore, they could get the potentials of all bodies within a certain region equal, or nearly equal, no discharge could take place between them. They might secure this by connecting all these bodies by means of good conductors, such as copper-wire ropes, but it was not necessary to do so, for it might be shown by experiment that if every part of the surface surrounding a certain region was at the same potential, every part within that region must be at the same potential, provided always that no charged body were placed within the region. It would therefore be sufficient to surround the powder mill with conducting material—to sheathe its roof, walls, and ground floor with thick sheet copper, and then no electrical effect would occur within it on account of any thunderstorm outside. There would be no need of any earth connection. They might even place a layer of asphalt between the copper floor and the ground so as to insulate the building. If the mill were struck it would remain charged for some time, and a person standing on the ground outside or touching the wall might receive a shock, but no electrical effect would be perceived inside, even by the most delicate electrometer. A sheathing of copper was by no means necessary in order to prevent any electrical effect taking place. Supposing a building were struck by lightning, it was quite sufficient to enclose it with a network of a good conducting substance. Then, again, if copper wire were carried round the foundations of a house, up the edges of the corners and gables, and along the roofs, this would probably by a sufficient protection for the building against any thunderstorm in this climate. The copper wires might be built into the walls to prevent theft, and they should be connected with any outside metal, such as lead or zinc on the roof, and with the rain-water pipes. In the case of a powder mill, it might be advisable to make the network closer, carrying one or two wires over the roof and down the walls to the wire at the foundation. If there were water or gas pipes entering the building from without, these must be connected with the system of conducting wires, but if there were no such metallic connections with distant points, it was not necessary to take any pains to allow the escape of electricity into the air; still less was it advisable to erect a tall conductor with a sharp point in order to relieve thunder clouds of their charge. It was hardly necessary to add that it was not advisable during a thunderstorm to stand on the roof of a house so protected, or to stand on the ground outside, or to lean against the wall.

ON GAUGING OF STREAMS.

By DAVID M. GREENE, C. E.

Transactions of the American Society of Civil Engineers.

In the examination of questions frequently arising among neighboring mill owners using the water power of our country streams, it almost always happens that the engineer is called upon to form an opinion—as to the adaptability of the machinery used to the available power of the stream, and as to the "reasonable use" of such power.

It is assumed that so much machinery may be employed, at any point upon any stream, as can be effectually and fully operated by the water flowing therein at its "ordinary stage." What, then, is the ordinary stage of a stream? We answer, that it is the minimum flow occurring during from eight to nine months of the year, excluding the three or four months of low water usually occurring during the late summer, early autumn and in mid-winter. In other words, machinery properly adapted to the flow of water in the stream upon which it is located, may run without interruption from a defective supply of water, during eight to nine months in each year.

The extent of the interruptions which are to be expected during the remaining three or four months, will, of course, depend upon the extent to which extreme low water falls below the ordinary stage, and upon the duration of the extreme low stage.

It is assumed that such an adaptation of machinery is a fair compromise between the condition of an amount of machinery adapted to the maximum flow, which would be subject to constant interruption throughout the entire year, and that of machinery adapted to the minimum flow, which, while able to run uninterruptedly, would involve a constant and very large waste of power, except during the generally brief period of extreme low water.

The charge of "unreasonable use" is usually made when, during low water, mill owners draw more than is naturally flowing in the stream, until their ponds are exhausted, or their heads reduced to such an extent as to necessitate the stoppage of their works, and then shut their gates for the purpose of filling their ponds; thus entirely suppressing, for a longer or shorter time, the flow of water, and of course, interfering with the operations of the machinery below.

Again the charge of "unreasonable use" is sometimes made by the manufacturers whose business requires them to run their machinery night and day, and who, therefore, require a constant and uniform flow of water; when their up-stream neighbors, running their machinery during the day only, draw down the water during the day, and at night shut down their gates in order to accumulate a supply of water for the following day, thus sending down an unusual and unnatural quantity by day, and almost entirely suppressing the flow at night.

It is not, however, my purpose to discuss the various and complicated questions growing out of the use of water power, but rather to indicate the means I employed in an important case, to determine the minimum flow of a stream, and its relation to the use by a cotton factory, as a means of ascertaining approximately, whether the quantity of water used by the factory was or was not greater than the ordinary flow of the stream.

In the case referred to, an improved Fourneyron turbine about eight feet in diameter was used, under a head of forty feet. This turbine was so carefully constructed, that the quantity of water used upon it could be determined very accurately, and the dam was tight.

The observations were made during the period of extreme low water, in summer, and in the following manner: *First* the pond being full to the crest of the dam—no water flowing over—the factory was started up and run to its fullest capacity, until the pond had been drawn down about two and a half feet. *Second*, the gate was then closed tightly, and the pond allowed to fill to the point at which it stood when the machinery was started. *Third*, the times required to draw down the pond and to fill it again were carefully noted.

These operations were repeated several times—drawing the pond down various distances, ranging from four inches to two and a half feet. While drawing down the pond, in each case, a determinate quantity of water was used by the turbine, which was equal to an indeterminate quantity stored in the pond, plus the indeterminate quantity flowing in the stream at the same time. While the pond was being raised to its former level, in each case, the above indeterminate quantity of water was being stored therein from the normal minimum flow of the stream.

In order to express the relations analytically, to eliminate the volume of water stored in and drawn from the pond during each experiment, to determine the relation between the volume flowing in the stream and the quantity used by the turbine, and to ultimately determine the minimum flow of the stream, we proceed as follows :

Let Q, equal flow of the stream, and Q', the flow through the turbine, in cubic feet per minute ; t' the time required to draw down the pond ; and t for pond to fill to original level, in minutes ; and V, the volume stored in and drawn from pond, during experiment, exclusive of flow of stream.

Then $V = Qt$, and the quantity used by the wheel, while drawing down the pond, $V + Qt = Qt + Qt' = Q't'$; when

$$\frac{Q}{Q'} = \frac{t'}{t+t'}; \text{ and } Q = Q'\left(\frac{t'}{t+t'}\right)$$

Several experiments were made, in which the value of $\frac{Q}{Q'}$ ranged from 0.65 to 0.69; showing that, at extreme low water, the stream furnished about 66 per cent. of the quantity of water required to run the factory continuously, at its full capacity; or considerable more than would be required to run at full capacity during ten hours of each day, provided the flow could be controlled during the night.

Similar experiments, made at the ordinary stage of the stream—or at any stage—when the flow is less than the quantity used upon the wheel, would furnish the relations between Q and Q' at those stages.

This method,—original with the writer—is believed to be far more satisfactory and to furnish much more reliable results, in cases similar to that herein described, than the rude and uncertain methods in which sections and velocities of the stream are taken, or where the discharge over dams is estimated.

NOTE ON THE MOST ECONOMICAL DEPTH OF STRAIGHT GIRDERS AND TRUSSES.

By EMIL ADLER, C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

It is a very unprofitable labor to deduce strictly mathematical rules for the selection of the most economical depth of girders and trusses, inasmuch as such rules would have very little practical value from various reasons, which I will briefly recite.

1/ Such rules or formulae would have to contain so many variable quantities, that their application would take more time, than any engineer, accustomed to such work, would occupy in making and eventually remaking a complete estimate. These variable quantities would have to be : the live load, the dead load, the panel length and the unit strains. These latter are different for tensile and compressive members, and again different for compressive members according to the proportion of the length to the least diameter of gyration, both tensile and compressive unit strains again varying with the different specifications.

2/ It would be impossible in such rules if they had to be in any way general and applicable to all spans, all kinds of details and every system, to introduce the least sections, which practically can be used, especially in compressive members, neither could all the many small and minor quantities be introduced, which remain constant with each special mode of constructing the details and hence with each building firm; but on the other side vary very much with different details and hence with every different building firm.

3/ The girders proper form after all only a part of the whole amount of material, and the floor system forms another essential part, and hence the panel length has to be selected; not so, that the material in the girders proper becomes a minimum; but so, that the combined material of trusses proper and floor system becomes a minimum. To introduce this into the rules in a general manner would require such a complication, that any engineer would become discouraged, and it has so far never been undertaken;

hence the panel length has always to be selected beforehand, and to this selection experience is the best guide.

Only a few reasons why such formulae would have little practical value have been briefly summed up, as I feel confident, that any engineer, who has ever made an estimate for a bridge, would never think of using such formulae. Nevertheless the deduction of such formulae is not altogether useless as it might develop, and certainly has developed relations between the lengths of different members, or, what is the same, certain angles for the inclined members, which in certain special cases lead to economy.

There exists, however, a simple relation, common to all systems of straight trusses, that is: trusses with two parallel horizontal chords; a relation between the quantity of material in the chords and in the Web system which must be fulfilled to insure the most economical depth. We will find that this relation is independent of the load, the unit strains and the least practically possible sections, and hence holds good for any special mode of construction. This relation has, as we shall see, too, the advantage of an astonishing simplicity, which I believe will be a recommendation to practical engineers.

Before undertaking the deduction of this relation, it will not be out of the way to point out distinctly what we are aiming at. Our aim is not from reasons above mentioned, a priori to determine the most economical depth, but after a strain sheet and bill of quantities have been made, after the system, the panel length and the depth have been chosen; to determine whether the chosen depth is the most economical or not and on which side has been erred. The writer believes, that the relation at which we shall arrive has in one special case been known from experience to many bridge engineers, but he is not aware that any proof of this relation has ever been given, nor that any allusion to its existence has ever been made.

We shall now at once enter upon our subject and, after first calling into mind the general criterion that any function becomes a minimum or a maximum, separately treat of plate girders and trusses.

The criterion, that any function $f.(h)$ of a variable h for a certain value of h becomes a minimum or a maximum is, that for a small positive or negative increment $\triangle h$ to the variable, the equation :

$$\lim. \frac{f.(h+\triangle h-f.(h)}{\triangle h}=\frac{d.f(h)}{d.h}=0$$

is fulfilled, or in plain language : a function $f\ (h)$ of a variable h becomes a minimum or a maximum for such values of h, that a small increase or decrease of this value does not perceptibly change the function.

PLATE GIRDERS.

a. Plate girders with constant section.—The web thickness of plate girders can easily be calculated from the maximum shearing strain in the neutral axis; but this calculation nearly always gives results practically too small, that is: such thickness of Web plate as could not be obtained and would require an impracticably close spacing of rivets; hence the thickness of the Web plate has to be assumed and is assumed dependent on the height; but the same for any height, which in each particular case can be chosen.

Let M be the largest moment of exterior forces, which determines the section, and S the maximum unit strain, then :

$$\frac{M}{S}=R=\text{Moment of Resistance.}$$

If we now have a plate girder, with the section of one flange equal F and consider the small part the web gives to R as equivalent to the loss in the rivet holes, as is generally the case and call t the thickness of the Web plate; then we have:

$$R=F.h \quad . \ . \ . \ . \ . \ (1)$$

Now the total area of the section is : $h.t+2F$, and this quantity has to be a minimum being proportional to the weight, hence :

$$h.t+2F=\text{function } h=f.(h)=\text{Minimum} \quad (2)$$

if we substitute F from (1) in (2) we get:

$$h.t+\frac{2\ R}{h}=f\ (h)=\text{Minimum} \quad . \quad (3)$$

here R is a known value $=\frac{M}{S}$, and we have :

$$\frac{d.f(h)}{d.h}=t-\frac{2R}{h^2}=0 \quad . \quad . \quad . \quad . \quad (4)$$

if we here again substitute R from (1) we get:

$$t-\frac{2F}{h}=0 \text{ or } h.t=2F \quad . \quad . \quad (5)$$

this equation (5) says:

We have the most economical depth of girder, when the weight of the Web is equal to the weight of the flanges; for $h t$ is the section of the web and $2F$ is the section of the two flanges, and with constant section these quantities are proportional to the weights.

Although the nature of this problem clearly shows, that for finite values of h the function has no maximum, we might still for this case prove that we really have a minimum and not a maximum; this is proved by showing, that the second differential coefficient is positive. We have from (4)

$$\frac{d^2.f(h)}{dh^2}=+\frac{4R}{h^3}$$

and as R is positive, and h, too, always positive, our function cannot for finite values of h have a maximum.

b. Plate girders with variable flange section.—Here the same remarks about the thickness of the Web plate as in the former case hold good.

If we now consider a plate girder of the height h and thickness of the Web t, and call the quantity or volume of material in the two flanges M_{fl}, and suppose the height to be altered with the small quantity $\triangle h$; then the strains in the flanges, and hence the section will be altered in the proportion $\frac{h}{h+\triangle h}$, and we have, l being the length of the girder, the total quantity of material:

$$f(h+\triangle h)=M_{fl}\frac{h}{h+\triangle h}+(h+\triangle h)t.l \quad (1')$$

$$f(h)=M_{fl}+h.t.l \quad . \quad . \quad (2')$$

by subtracting (2′) from (1′), and dividing by $\triangle h$, we get:

$$\frac{f.(h+\triangle h)-f(h)}{\triangle h}=-M_{fl}\frac{1}{h+\triangle h}+t.l \quad (3')$$

$$\text{lim.}\frac{f.(h+\triangle h)-f.(h)}{\triangle h}=-\frac{M_{fl}}{h}+t.l=0 \quad (4')$$

or: $M_{fl}=h.t.l$ (5′); this says: *for the most economical depth the quantity of material in the flanges must be equal to that in the Web*; as $h t l$ is the volume of the material in the web.

We have here exactly the same relation as we had for plate girders with constant section, and in fact the same deduction as we have applied here holds good for the former case, which was only treated separately on account of the greater practical interest attached to it.

It needs no proof, that in case the weight of the Web material is greater than the weight of the flange material in these two cases, the height, that has been chosen is too great and vice versa. Practical engineers will know in which cases this astonishingly simple relation is of any value, as in many cases, perhaps the most frequent, the height, which can be chosen, lies between very narrow limits, and the most economical depth lies without these limits. In such cases our relation is of course of no direct use; but the knowledge of its existence might still be a valuable guide.

TRUSSES.

We now come to a series of cases, where more practical value will be attached to a similar simple relation as the height is not generally limited here. I am confident that most bridge engineers will be agreeably surprised to find here an analogous relation, which is quite as simple as the foregoing.

In the following deduction some assumptions must naturally be more or less concealed; but their justification will be more easily understood when they are pointed out after the deduction has been made, and we shall then, with the limits of the correctness of our assumptions, get the limits for the application of our relation.

For the deduction I shall, as an illustration, use a rectangular truss with single intersection and vertical end post, merely for the reason, that I have to use some illustration; but a way of deduction and a notation shall be used, which will plainly show the generality of the relation to any body acquainted with the simple calculation of strains in straight trusses.

The variable quantity of material in a truss, when the necessary data for calculation, as span, live load per foot, unit strains, etc., are given, and the panel length, general design and system of details have been chosen, is a function of the only remaining independent variable, namely, the depth h.

If we now call M the whole amount of variable material we have :

$$M = f.\ (h) = \text{Minimum}.$$

The nature of this function can be determined thereotically, but not practically, as has been shown at the commencement of this paper; but without knowing the nature of this function we can find a relation, which must exist in order to make the function a minimum.

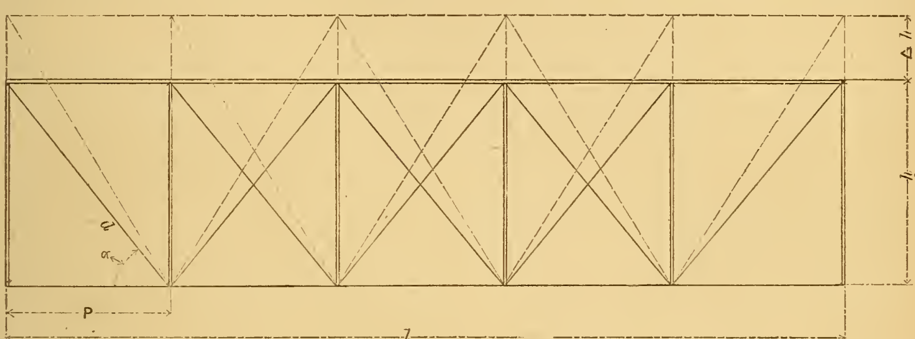
If we have any straight truss of span l, panel length p and height or depth h, we have a certain amount of material in the chords, in the vertical members and in the inclined members or diagonals.

We shall call these quantities:

M_c = Material in chords.

M_v = Material in vertical members.

M_i = Material in inclined members.



If we now alter the height with the small quantity $\triangle h$, all the above quantities will change and we shall see separately for each of them in what proportions they are changed.

1/ The strains in the vertical members have not changed and hence their sections have remained the same, and as their lengths have been altered in the proportion $\frac{h+\triangle h}{h}$; the quantity of material in these vertical members has altered in the same proportion, and is after the change of height

$$M_v \frac{h+\triangle h}{h} = M_v + M_v \frac{\triangle h}{h}$$

2/ The strains in the horizontal chord members, and consequently their sections, have been altered in the proportion $\frac{h}{h+\triangle h}$, and as the length of these members has been unchanged the quantity of material has been altered in the same proportion as the sections and is therefore after the change :

$$M_c \frac{h}{h+\triangle h} = M_c - M_c \frac{\triangle h}{h+\triangle h}$$

3/ The inclined members have changed their length, as well as their sections, and therefore the material has changed in proportion of the product of proportions of changes in length and changes in section.

If we call the length of a diagonal d, before the change, and its inclination to the horizontal chord α, then its length will be $d + \triangle h \sin \alpha$ when the height is changed with the small amount $\triangle h$ and the proportional change is

$$\frac{d+\triangle h \sin. \alpha}{d}$$

The strains have altered in the proportion

$$\frac{d+\triangle h \sin. \alpha}{h+\triangle h} \cdot \frac{h}{d}$$

and the quantity of material has changed in the proportion of the product of these two proportions and is therefore after the change in height:

$$M_i \left(\frac{d+\triangle h \sin. \alpha}{\alpha}\right)^2 \cdot \frac{h}{h+\triangle h} = M_i + M_i \left(\frac{h \triangle h^2 \sin.^2 \alpha + 2\, h.d \triangle h \sin. \alpha - d^2 \triangle h}{d^2 h + d^2 \triangle h}\right)$$

We have now :

$$f(h+\triangle h)=M_v+M_v\frac{\triangle h}{h}+M_c-$$

$$M_c\frac{\triangle h}{h+\triangle h}+M_i+$$

$$M_i\left(\frac{h\triangle h^2\sin.^2\alpha+2hd\triangle h\sin.\alpha-d^2\triangle h}{d^2.h+d^2\triangle h}\right)$$

$$f(h)=M_v+M_c+M_i$$

Subtracting and dividing by $\triangle h$, we get:

$$\frac{f(h+\triangle h)-f(h)}{\triangle h}=M_v\frac{1}{h}-M_c\frac{1}{h+\triangle h}$$

$$+M_i\left(\frac{h\triangle h^2\sin.^2\alpha+2h.d.\sin.\alpha-d^2}{d^2.h+d^2\triangle h}\right)$$

$$\text{or lim.}\frac{f(h+\triangle h)-f(h)}{\triangle h}=\frac{M_v}{h}-\frac{M_c}{h}$$

$$+M_i\frac{2h\sin.\alpha-d}{d}$$

Now for a minimum, this must be equal to zero, and multiplying by h and considering that $\sin.\alpha\frac{h}{d}$, we get:

$$M_v-M_c+M_i\frac{2h^2-d^2}{d^2}=0$$

or $M_v-M_c+M_i(\sin.^2\alpha-1)=0$, or

$$M_v+M_i\cos.(180°-2\alpha)=M_c \quad \text{(I)}$$

that is in ordinary language.

For the most economical depth, the material in the two chords together must be equal to the material in the vertical members, plus the material in the inclined members, the latter multiplied by cosinus $(180°-2\alpha)$, *where* α *is the angle the inclined members make with the horizontal chords.*

It is considered evident, that in case: M_c is larger than M_v+M^i cosinus $(180°-2\alpha)$ the chosen depth is too small, and *vice versa* if M_c is smaller, then M^v+M^i cosinus $(180°-2\alpha)$ the chosen depth is too great.

Before we proceed with the interpretation of this exceedingly simple relation, we must make a few remarks on its generality.

The material of which we have been speaking is evidently only the variable part of the material in each set of members, and does not include the material used in joints, splices, etc., which would remain the same for a slight change in height; but the variable part is easily selected from a bill of quantities.

In a triangular truss, with no vertical members, M_v is equal zero, when the triangular truss has vertical ties from the upper joints, or vertical posts from the lower joints, to shorten the length of the compressive top chord members, the material in these would be equal M_v. In a truss with more than one system of diagonals, the end diagonals, which have a different inclination from the other diagonals, have of course to be multiplied by their corresponding coefficient; in trusses with inclined end posts or sloping end diagonals, these end posts or diagonals come in under M_i.

In this way, and considering the mode of deduction, we see that our relation is quite general and holds good for any kind of straight truss.

We must now proceed with the discussion of our relation:

$$M_v+M_i\text{ cosinus }(180°-2\alpha)=M_c \quad \text{(I)}$$

A mere look at this relation shows, that the second member can be positive, zero and negative for different values of α. The point of transition where this member disappears is of special interest.

The second member disappears for

cosin $(180°-2\alpha)=0$, or for $\alpha=45°$

in this special case our relation assumes the very simple form $M_v=M_c$, that is; *when in a rectangular truss* 45° *shall be the most economical angle then must the material in the chords in amount be equal to the material in the posts.*

When α is smaller than 45° the second member becomes negative, and when α is larger than 45° then the second member is positive, or we might see: *if the diagonals have an angle of inclination less than* 45° *the material in the diagonals decreases for an increase in height*, whereas; *if the diagonals have an inclination to the horizontal chord larger than* 45° *the Web material increases with an increase of height.*

As now in American bridges with long pannels the weight of the chord material will nearly always exceed the weight of the vertical members, we see that for such bridges 45° is not an economical angle but the diagonals would have to make a larger angle with the horizontal chords.

If the angle was still smaller the weight in the chord + part of the weight of the diagonals would have to be equal to the weight in the posts.

Bridges with many and short panels require a small depth, as here the weight of the posts and part of the diagonals form a greater part of the whole weight, than they do in bridges with few and long panels.

Although as already stated it is not our aim to try a priori to determine the most economical depth, we might still draw a few simple conclusions from our relation. I shall only point out some of these conclusions, as every engineer might easily himself be able to see their justification.

We might see, that the most economical depth is smaller for deck bridges, than for through bridges as the strains on the posts are heavier in the former, than in the latter, (we shall later see another reason). We further see that rectangular trusses with inclined end-posts (or sloping end diagonals) require smaller depths than such with vertical end posts; we see that trusses with more than one Web system might be built deeper than such with only one system of diagonals; we see too that continuous bridges ought to be built lower than single girders; this fact was first pointed out by Mr. Charles Bender.

We have still to consider one special case, namely, the triangular truss with no vertical members, and with an angle of inclination of 45°.

In this case our relation assumes the seemingly absurd form $Mc=0$; but this is not at all absurd, but shows us plainly, that 45° can never be an economical angle for triangular trusses; we could see this in another way easily. We have seen that for $\alpha=45°$ a slight change in the height does not alter the quantity of material in the diagonals, but such a change would change the material in the chords, and if we were to increase the height we would diminish the material in the chords and not change it in the *Web* at all and hence a higher truss would be more economical. We might easily from our relation draw the conclusion that for triangular trusses the most economical depth is a good deal greater than for rectangular trusses.

It is now an easy work to make out a small table of values of cos. $(180°-2\alpha)$ for different values of α and with such a little table at hand it is an easy and quick work with aid of a strain sheet and bill of quantities to find out if the most economical depth has been chosen or not, and eventually in which direction the assumed depth has to be changed, in order to make the truss more economical.

Before concluding, we have yet to justify the assumptions upon which our deductions have been based :

1/ We have assumed, that the horizontal and transverse bracing is a constant part of the whole material.

As regards the horizontal bracing this is correct ; for although this bracing varies slightly for great changes in depth of truss, it remains constant for small changes and the reader will bear in mind that our deduction is based upon the consideration of extremely small changes; to this assumption, hence, no objection can arise. As regards the transverse bracing, we can say exactly the same as we said about the horizontal bracing, as far as through bridges are concerned; but with deck bridges the case is another.

To deck bridges the length of the transverse rods change with the height, and had hence to be introduced into our calculation; they can be very easily introduced and were only left out for the sake of simplicity and generality. Any how the transverse bracing would have a very small influence, and would tend to make deck bridges a little lower.

2/ We have assumed that for an extremely small change in depth, the dead load does not alter; I cannot imagine that anybody should object to this assumption.

3/ We have assumed that a small alteration in height would not alter the sections in the compressive Web members as long as the strains remain the same. This assumption is justified by the fact, that a very great part of these members have so small sections that they would not be changed, and for the others the radius of gyration could be changed in the same proportion as the length.

In case the radius of gyration for these should be kept the same the material in the compressive Web members would in our relation still have to be multiplied with a coefficient, and in case of vertical posts this coefficient would have to be:

$$1+\frac{2}{1+3600\,n^2}$$

where n is the ratio of the least radius of gyration to the length. This coefficient is found by using Rankine's formula and a similar deduction to the one which gave us our relation.

4/ We now come to the point, which will indicate the limits for the application of our relation. We have assumed that we could vary our chord sections according to the difference in strain arising from a change in height; although we can nearly always do so with the tensile chord it is not possible for the compressive chord, as we cannot construct such a chord with less section than a certain minimum, which cannot be exactly stated as it may be varied with different modes of construction and with the shapes of iron at disposition. This section would determine the span at which we could commence to vary our section, and I should say for a single track railway bridge under an average specification give us the lower limit for the application of our relation, at about 60′ span, and for light highway bridges with narrow roadway, this limit would lie still higher. An upper limit does not exist. I must still make the, perhaps, unnecessary remark that this relation does not apply to any kind of combination bridges, and for wooden bridges the assumption we have made would scarcely hold good for spans lower than say, 150′ and larger purely wooden trusses will perhaps never more be built, therefore we have only to apply our results to wrought iron bridges.

I hope the relation we have found will, from its simplicity and easy application, be of value to practical bridge engineers.

APPENDIX.

Cotang. α is always a known value as it is the coefficient for the calculation of the chord strains.

I therefore annex a little table giving the corresponding values of cosinus $(180°-2\alpha)$ or the coefficient with which, in our relation, the material in the inclined members has to be multiplied, for given values of cotang α:

Cotang. α.	Cos. $(180-2\alpha)$.	Differences.
0.4	+0.72	.12
0.5	+0.60	.13
0.6	+0.47	.13
0.7	+0.34	.12
0.8	+0.22	.11
0.9	+0.11	.11
1.0	+0.00	.10
1.1	−0.10	.08
1.2	−0.18	.08
1.3	−0.26	.07
1.4	−0.33	.06
1.5	−0.39	.05
1.6	−0.44	.05
1.7	−0.49	.04
1.8	−0.53	.04
1.9	−0.57	.03
2.0	−0.60	

The third column gives differences, which are useful for the interpolation for intermediate values of cotang. α.

ON EVAPORATION AND PERCOLATION.

By CHARLES GREAVES, M. Inst. C. E.

Abstract of Minutes of the Proceedings of the Institution of Civil Engineers.

Whether the descent of rain or the ascent of vapor be the more important natural phenomenon may perhaps be a difficult question to decide. There can, however, be no doubt that, hitherto, the study of the first and the measurement of rainfall have received the greater degree of attention. It is with a view to obtain a more systematic, and at the same time practical, series of observations of the latter, that the author has undertaken this paper. After having carried on such observations, he has found them afford new and important information; and he hopes to secure cooperation so as to enlarge the exact knowledge of atmospheric evaporation, now unfortunately very limited.

The quantity of water which the inhabitants of this earth, in any part, have to deal with is the result of the operation of two series of forces, one tending to increase, the other to diminish it. The measurement of rainfall, by the quantity collected, has always this practical advantage, that it is total and real, and the water in hand is an accomplished fact; but the knowledge of evaporation, as now generally acquired, is merely a deduction from the capacity of the atmosphere to evaporate. The endeavor of the author has been to give this also a practical form, and at the same time to avoid prejudice to the observations by a too frequent emptying of the measuring vessel, or from local and accumulated heat causing undue evaporation in it.

It is the purpose of the author to enter into a discussion of maxima and minima—of total and periodic quantities, such as those of

Rain falling;
Rain percolating through ordinary ground, and re-evaporated from it;
Rain percolating through sand, and re-evaporated from it;
Water evaporated from a water surface by a natural process, and their co-relation.

Ever since the year 1850, the author has felt how desirable it would be to confirm the interesting reports then given by Mr. Dickenson to this institution, on the percolation of rain through a medium representing natural soil, and he resolved to establish a similar guage and register. The guage was set in October, 1851, but suffered some interruption previous to the beginning of 1855, since which time the register has been maintained continuously.

The gauge is on the principle known as a "Dalton Gauge," and is thus constructed: A strong slate, open-topped, water-tight box or tank, with an area of one square yard, and one yard deep, has connected to the middle of its bottom a lead pipe, which is led to another fixed vessel with a close bottom, set upright as a receiver, and with its base placed several feet below the tank. A glass guage pipe is fitted to the side of the receiver, with stop and outlet cocks and a graduated scale, and the whole of the receiver is easily protected from frost. The slate tank is sunk into the ground, the inside of the bottom is slightly coned with cement to the mouth of the outlet pipe, and the tank is filled with soil or earth to within two inches of the top. The soil is turfed over, kept level, and the grass is occasionally cut; nothing is done to tighten the soil, and worms are sometimes seen. The water in the receiver never reaches the level of the bottom of the tank, the soil of which is underdrained.

The "Dalton Guage" has no overflow, and water has never been seen to accumulate on the surface of the earth or grass. It is intended that all rain that falls on it should soak in. The soil has once been taken out of the tank and put in again.

A rain guage of equal superficial area, but only one foot deep, was fitted at the same time beside the "Dalton Guage," and the two are under like conditions in all respects.

In the year 1860, another guage, similar to the "Dalton," was established, and filled entirely with fine sand. This was with a view of getting at a definite maximum of percolation. The sand is also underdrained, and is therefore never in a state of stagnant saturation.

The observations from the above gauges did not afford all the knowledge required by the engineer to ascertain the amount of water available out of any known rainfall. They gave the rainfall, the percolation, and, by deduction, the evaporation, both from sand and from a surface of turf; but the evaporation from a water surface is wanted. This has been practically measured, since the end of 1859, in a similar guage, one yard square and one foot deep, which has been kept afloat and partially immersed in a quiet part of a flowing stream. The surface of the water within is always below that of the water without, and from three inches to seven inches is found to be the best depth, this being ascertained periodically with a dip-stick. It is exposed to all weathers, and any addition or abstraction of water is duly recorded, none being made without necessity.

By combining together the observations in the ordinary closed rain guage and those of the floating gauge, an absolute measure of evaporation, from a water surface representing as nearly as can be the surface of a river, lake, or reservoir, is obtained.

The gauges stood at Lee Bridge, in the valley of the Lee, one and a half miles west of, and six miles north from the meridian of Greenwich. The surface is about ten feet above Trinity high-water level. They are read at 9 A.M., and the records are booked to the day on which they are read.

By the use of the floating gauge the series of comparisons is greatly extended, and the relative proportion of evaporation from land and from water during varying seasons is conspicuously shown. It is not of course possible to affirm that the soil in the "Dalton" gauge is strictly representative. It was intended to resemble common Hertfordshire land, and was made up of soft earth with loam, gravel, and sand, all well mixed up beforehand and trodden in. Neither is it possible to assert that in every respect, and, at all times, the evaporation guage has as accurate a relation to evaporation as rain guages have to rain. Indeed, simple as they are, they have given occasion for a great variety of opinions.

The measurements in the floating guage show directly a gain or a loss of water, and by combining the observations with those of the ordinary closed rain guage the total evaporation is known. A rise of level in the water of the float is recorded as R, a fall as E. The formula for the use of the gauge is then total evaporation from water = R. G. (that is rain guage) $\mp \frac{R}{E}$. A Table of total evaporation is thus obtained.

Comparison with the records of neighboring rain gauges, as published by Mr. G. J. Symons, confirms the accuracy of the Lee Bridge returns. The average fall of rain at twelve stations in London for the seven years, 1864 to 1870, all agreeing closely together, was 24.486 inches; and at Lee Bridge, for the corresponding period, 23.934 inches.

Condensation of moisture on the surface of the sand guage is of frequent occurrence. Only in three years out of the fourteen has the annual evaporation from water exceeded the rainfall, viz., in 1861, 1864, and 1868; in the year 1870 it was the same, and in the remaining years rain was in excess. The rise of water in a supposed tank open to rain and evaporation has been 71.5 inches in fourteen years. The percolation through ordinary ground has been 26.57 per cent. of the rainfall in twenty-two years, and the evaporation 73.42 per cent. of the rainfall. The evaporation from a surface of water has been 77.77 per cent. of the rainfall: still in 1861, 1864, and 1868, the evaporation exceeded the rainfall. In such years the inability to store water, and the loss of store, are severely felt. The actual disappearance of a depth of 11.375, inches of water in seven months in 1868, of 10.625 inches in five months in 1870, of 9.375 inches in five months in 1864, and of 9.125 inches in seven months in 1861, from the surface of an inclosed area of water, by simple evaporation, is a feature that may disturb many calculations. A comparison of tables of evaporation and of rainfall is of great value to an engineer, as showing what can and what cannot be retained in an open receptacle subject to atmospheric influences. If evaporation were the purpose or the end sought, more effect could be attained by excluding the rain, if such could be done without hindering the access of sunshine and of air, but that is not the object. Clearly if an open vessel loses water it does so notwithstanding the rain. Evaporation is the difference between the amount of water in the covered and uncovered rain gauge if that in the latter gauge rises or gains, but the sum of the covered and uncovered gauges if that in the latter falls. If, therefore, evaporation is shown notwithstanding the inclusion of rain, it follows that the theoretical power of the air to evaporate is equal to the same amount inclusive of the rain gauge. The author has not endeavored to draw out the correspondence between humidity and evaporation. His object has been to get at a real result by a practical method, and so to design the apparatus that it may be capable of reproduction by other observers. With this view he has established another gauge, three feet square, and has floated it in a second five feet square. This method is within the reach of all inquirers, and independent of rivers or mill streams and their special difficulties.

PERCOLATION.

The yield of springs, or the abundance

of water in a river, where the river is fed from springs, will be found, from a comparison of the tables in the Appendix, to be dependent more closely on percolation through the soil than on the mere rainfall; indeed it will be found to correspond with percolation. For, whereas the variations in annual rainfall are as 2.33 to 1, being 37.166 inches in 1872 as compared with 15.891 inches in 1864, the annual percolation through ground varies as $3\frac{1}{2}$ to 1, the greatest being 12.587 inches, the least 3.761 inches, in fourteen years. The percolation through sand varies as 7 to 4, being 30.050 inches in 1872, and 12.636 inches in 1864. The evaporation from a surface of water varied only from 26.933 inches to 17.332 inches, being nearly as 7 to $4\frac{1}{2}$ in fourteen years, but it is the intermitting character and its total absence in summer which are so specially characteristic of percolation. Great percolation supervenes on the thawing of snow, and the greatest is due to frequent thaws of small falls of snow. For many consecutive months there is often no percolation whatever, and the monthly range varies from 3.5 inches to nothing. Five times there has been no percolation for seven continuous months, and twice more for six months, and only in one year, 1860, has there been percolation every month.

A thoroughly underdrained soil, if sufficiently flat, would rarely produce any flood, that is, no water passing off by open water-courses. It would resemble the percolation gauge. The result of such underdraining on rivers would be to diminish floods, without lessening the annual discharge of water, and therefore to maintain the flow in dry seasons. Hollow draining does not diminish the perennial flow of rivers as much as improved superficial draining.

The author believes thirty-six inches to be ample depth for a percolation gauge, and he is inclined to think that all water that passes a depth of twenty-four inches in the earth is safe from loss. It is, indeed, doubtful whether in the latitude and temperature of London capillarity has more than a negative action beyond twelve inches in depth. Probably on a moderately free soil the depth from which water is raised by capillarity is but a few inches, and in this may lie the difference in the healthiness of soils, the higher capillary power of a clay soil producing a constant summer exhalation. Whether the substrata underlying a clay soil are really deficient in moisture is a question not sufficiently determined; but the fact, if proved, would be an additional reason for hollow draining, speaking in the interest of agriculture or vegetation.

In order to bring the data into better practical use, the author has reduced each of the tables (omitted for want of space) into a twelvemonthly series, so as to show at the end of every quarter the result for the twelve months previous. By this means a series is produced with a continually uniform term, in which all the seasons take part. The effects of the four previous seasons, which always leave their mark on the earth, on vegetation, and on the climate, are thus continually imported into view. It does not appear needful to carry this form of table over a greater interval. It is possible that percolation, or the absence of it, at one period may have an influence extending over more than twelve months, but it is not habitually so. A wet winter will give abundant springs in the following autumn; but if that is followed by a dry winter, the latter will obliterate the effect of the previous wet winter.

The general conclusions from these records, and the most prominent results observable, are then:—The magnitude of percolation through sand at all times —the smallness of percolation through earth on the whole—the consequent magnitude of evaporation—the entire absence of percolation in warm summer weather—the excess of evaporation from ground over evaporation from a surface of water in winter, and from a surface of water over evaporation from ground in summer—the small thickness of earth under which the water may be considered safe from loss—great variations observable in the twelvemonthly percolation, the maximum reaching ten to eleven times the minimum. Evaporation from earth approaches uniformity from year to year. It hardly reaches 2 to 1, seldom exceeds twenty-five inches or falls below seventeen inches. Evaporation from water is the most uniform of all, the range only just exceeding 3 to 2, the maximum being 27 inches and the minimum 17 inches.

Districts more or less rainy have their special characteristics, known occasionally by popular observation and report, and more exactly where any system of recording has prevailed. Thanks to Mr. Symons' excellent and laborious records, the whole of Great Britain may now be mapped out into rain districts or zones; and if the rate of evaporation were equally well known, it would be possible to distinguish between dry and damp districts. The standard of evaporation and of percolation for any place will become hereafter as much a subject of study as that of rain.

Predictive meteorology is far removed from practical engineering, nevertheless the percolation gauge gives a most certain scale of the future state of springs. The delivery flow of water from springs in the autumn, and consequently the fulness of rivers so fed, is maintained by the rainfall of the previous winter. Summer percolation is nil; and rivers, except as influenced by the rain of the time being, will be short indeed in September and October, if the percolation of rain has not been considerable in the previous December, January or February. Intermittent springs are developed according to the previous percolation, and not simply according to the rainfall, with which they sometimes do not agree at all. Heavy rains in summer may afford no percolation, and a whole year may be considered wet, and yet not be one in which springs are fed. The quantity of water evaporated gives a scale of the capacity of the atmosphere for evaporation, and consequently of the degree of its humidity.

An artificial table for the Home Counties, gives 18 inches of evaporation from the surface of the ground, out of 25 inches of rainfall; that is 72 per cent., or 28 per cent. for percolation. The evaporation from a surface of water is at the same time 82 per cent., leaving 18 per cent. as the gain in rain. The percolation feed, therefore, in what is assumed to be a thoroughly-drained soil and subsoil, is greater than the direct feed on open water alone, as deduced from the balance of rain and evaporation.

After all, it may be argued that the author's gauge is not the best, is not correct, is liable to accumulated and accidental heat—the bane of so many gauges; or that it is open to a double defect, of evaporation in excess in hot weather, and in defect in cold weather. Doubtless water in a shallow vessel is liable to become heated; but the surface of any water becomes heated, and the penetration varies with the depth, transparency, foulness, weediness, wind, waves, and movement, if a river, a mill-stream, or a slow canal, or a ponded river. The author is sanguine that his gauge is a good mean representative of all conditions. It was for some years in a more exposed situation, and appeared during a gale to be in so great danger of receiving the spray from waves dashing against the sides, that it was removed into a more quiet place. Certainly the less oscillation it suffers the better, as in an opposite way the wetting and drying of the inner surfaces must be a source of error, but a counter-action may be found in condensation at other times. Cases of negative evaporation in the floating gauge—that is, of increment above the rainfall—are not numerous; only three occurred in the fourteen years. But on the sand gauge it is frequent, owing to the great degree of cold which the sand evidently acquires. This induced cold causes condensation. Reverse evaporation, or more percolation than rainfall, has never appeared from the ground gauge.

Cast iron Chilled Wheels.—The use of chilled cast iron wheels for railway carriages and trucks is so universal in the United States that on most of the railways no other class of wheel is used to any extent for either passenger or freight rolling stock. In making these wheels, the greatest improvement of late has been the addition to the pig iron in the cupola, a certain proportion of Bessemer steel, usually the crop end of rails, an improvement which was introduced by Mr. Hamilton, and which it is found not only improves the chilling properties of the wheel, but also adds greatly to its strength, and even allows of anthracite pig iron being employed instead of the charcoal iron which previously was always used.

ON THE ORIGIN OF WINDINGS OF RIVERS OF ALLUFIAL PLAINS, WITH REMARKS OF THE FLOW OF WATER ROUND BENDS IN PIPES.

By Prof. JAMES THOMPSON, LL. D., F. R. S. E.

Proceedings of the Royal Society.

In respect to the origin of the windings of rivers flowing through alluvial plains, people have usually taken the rough notion that when there is a bend in any way commenced, the water just rushes out against the outer bank of the river at the bend, and so washes that bank away, and allows deposition to occur on the inner bank, and thus makes the sinuosity increase. But in this they overlook the hydraulic principle, not generally known, that a stream flowing along a straight channel and hence into a curve must flow with a diminished velocity along the outer bank, and an increased velocity along the inner bank, if we regard the flow as that of a perfect fluid. In view of this principle, the question arose to me some years ago:—*Why does not the inner bank wear away more than the outer one?* We know by general experience and observation that in fact the outer one does wear away, and that deposits are often made along the inner one. *How does this arise?*

The explanation occurred to me in the year 1872, mainly as follows:—For any lines of particles taken across the stream at different places, and which may be designated in general as A B, if the line be level, the water pressure must be increasing from A to B, (inner side of bank to outer side), on account of the centrifugal force of the particles composing that line or bar of water; or what comes to the same thing, the water-surface of the river will have a transverse inclination rising from A to B. The water in any stream-line,* at or near the surface, or in any case not close to the bottom, and flowing nearly along the inner bank, will not accelerate itself in entering on the bend, except in consequence of its having a *fall of free level* in passing along that stream-line†.

But the layer of water along the bottom, being by friction much retarded, has much less centrifugal force in any bar of its particles extending across the river; and consequently it will flow sidewise along the bottom towards the inner bank, and will, part of it at least, rise up between the stream-line and the inner bank, and will protect the bank from the rapid scour of that stream-line and of other adjacent parts of the rapidly flowing current; and as the sand and mud in motion at the bottom are carried in that bottom layer, they will be in some degree brought in to that inner bank, and may have a tendency to be deposited there.

On the other hand, along the outer bank there will be a general tendency to descent of surface-water which will have a high velocity, not having been much impeded by friction; and this will wear away the bank and carry the worn substance in a great degree down to the bottom, where, as explained before, there will be a general prevailing tendency towards the inner bank.

Now, further, it seems that even from the very beginning of the curve forward there will thus be a considerable protection to the inner bank. Because a surface stream-line, or one not close to the bottom, flowing along the bank which in the bend becomes the inner bank, will tend to depart from the inner bank at the commencement of the bend, and to go forward directly, or by some such course, leaving the space between it and the bank to be supplied by slower-moving water which has been moving along the bottom of the river perhaps by some oblique path.

* This, although here conveniently spoken of as a stream-line, is not to be supposed as having really a steady flow. It may be conceived of as an average stream-line in a place where the flow is disturbed with eddies or by the surrounding water commingling with it.

† It must be here explained that by the *free level* for any particle is to be understood the level of the atmospheric end of a column, or of any bar, straight or curved, of particles of statical water, having one end situated at the level of the particle, and having at that end the same pressure as the particle has, and having the other end consisting of a level surface of water freely exposed to the atmosphere, or else having otherwise atmospheric pressure there; or, briefly, we may say that the *free level* for any particle of water is the level of the atmospheric end of its *pressure-column*, or of an equivalent ideal pressure-column.

It is further to be observed that ordinarily or very frequently there will be detritus traveling down stream along the bottom and seeking for resting-places, because the cases here specially under consideration are only such as occur in alluvial plains; and in regions of that kind there is ordinarily*, on the average, more deposition than erosion. This consideration explains that we need not have to seek for the material for deposition on the inner bank in the material worn away from the outer bank of the same bend of the river. The material worn from the outer bank may have to travel a long distance down stream before finding an inner bank of a bend on which to deposit itself. And now it seems very clear that in the gravel, sand, and mud carried down stream along the bottom of the river to the place where the bend commences, there is an ample supply of detritus for deposition on the inner bank of the river even at the earliest points in the curve which will offer any resting place. It is specially worthy of notice that the oblique flow along the bottom towards the inner bank begins even up stream from the bend, as already explained. The transverse movement comprised in this oblique flow is instigated by the abatement of pressure, or lowering of free level, in the water along the inner bank produced by centrifugal force in the way already explained.

* That is to say, except when by geological changes the causes which have been producing the alluvial plain have become extinct, and erosion by the river has come to predominate over deposition.

It may now be remarked that the considerations which have in the present paper been adduced in respect to the mode of flow of water round a bend of a river, by bringing under notice, conjointly, the lowering of free level of the water at and near the inner bank, and the raising of free level of the water at and near the outer bank relatively to the free level of the water at middle of the stream, and the effect of retardation of velocity in the layer flowing along the bed of the channel in diminishing the centrifugal force in the layer retarded, and so causing that retarded water, and also frictionally retarded water, even in a straight channel of approach to the bend, to flow obliquely towards the inner bank, tend very materially to elucidate the subject of the mode of flow of water round bends in pipes, and the manner in which bends cause augmentation of frictional resistance in pipes, a subject in regard to which I believe no good exposition has hitherto been published in any printed books or papers; but about which various views, mostly crude and misleading, have been published from time to time, and are now often repeated, but which, almost entirely, ought to be at once rejected.

DAMS FOR RESERVOIRS.

By WM. J. McALPINE, C. E.

Journal of the American Society of Civil Engineers.

In regard to the construction of earthen dams for reservoirs; below is a copy of the specifications for restoring the earthen dam at Worcester. These are full enough to explain my views of how an earthen dam should be built.

I have a letter from one of our most experienced and judicious members, in which he says: "It is a mortifying fact that so many of the dams built by our engineers in this section have failed, though those built by farmers and mill-owners stand safe."

Another said to me: "It is an accident if any earthen dam which has a 'spiling wall' does not fall." And another, referring to river dams of stone or wood, said: "They can never be considered safe until they have been twice carried away" (*i. e.*, at each end).

Earthen dams rarely fail from any fault in the artificial earth work and seldom from any defect in the natural soil. It, the latter, may leak, but not to endanger the dam. In ninetenths of the cases the dam is breached along the line of the water outlet passages.

The "spiling walls," which are put in

so many earthen dams, extending the whole length of the embankment and form a base into the tight natural soil and up to a level above the water in the reservoir, is usually made of rubble stone laid in cement with smooth faces.

Such walls will not perceptibly settle, but the best built puddle placed alongside will settle considerably, and there will always be a vertical crack along the whole length and height and at both faces of the wall.

If there should happen to be any place in the upper half of the dam which leaks, these cracks will conduct the water to an indefinite distance along, under and on both sides of the wall, to some leaky portion in the lower half where the water can escape.

A mere film of water is sufficient to carry the whole pressure (not volume) from the lake, and the water escaping in muddy sweat drops is gradually carrying with it the light soil in solution and enlarging the passage until an increase of quantity takes up the earth in suspension, and the orifices are then rapidly enlarged and a breach threatened.

Hence such cut-off walls become sources of danger. The two materials (masonry and earth) should not be used together if it can be avoided, or if so used, extraordinary care should be taken to prevent even a film of water along the line of union.

The outlet passages must be of masonry or of iron, and should rest on and be enveloped in masonry, and extending transversely through the dam is a source of peculiar danger.

Water in motion "abhors an angle" and any head can be destroyed by forcing the water to turn a sufficient number of abrupt angles, at each of which the velocity is lessened, the quantity (leakage is less, the "solution" or "suspension" is less and the danger of breakage is diminished and, with a sufficient number, is prevented.

Wherever walls of masonry are in contact with earth a film of water communicating with that in the reservoir is liable to occur. The surfaces of these walls should be made as rough and irregular as possible to produce as many of these angles as possible.

The puddle walls are always founded into a trench in the natural soil which should be broken up, and it should also be "toothed" both horizontally and vertically when the wall is *stepped* up on the sides of the ravine.

Under the whole base of the embankment, or, at least, that portion from under the lower top angle to the foot of the water slope, should be prepared by removing the pervious or decaying matter by breaking up the natural soil, and by stepping up the sides of the ravine, but also by several "toothed" trenches across the bottom and up the sides.

Forty years ago, Mr. Jervis introduced the modern system of building earthen banks, but before that time the "old school" engineers built earthen dams which rarely failed. Our modern practice requires the artificial earth work to be made with extraordinary care, but then it must always be based upon the natural soil. Now we take this same soil, select it carefully, moisten and compact it at great expense, and yet it is subjected to less pressure than the underlaying natural soil. Is all this care necessary? I never heard of a case where a dam failed from an imperfection in the artificial earth work, even if built by a "farmer." Leakages and destruction come from an imperfect connection between the artificial and natural earths.

The failures of earthen dams from overflow are not uncommon. No such dam is safe unless it has an overflow long enough to discharge the heaviest rain fall (increased by melting snow) without resort to the manual operation of opening gates, etc., before the water can rise to within three to five feet of the top of embankment. The attendant may be taken suddenly sick, or may be absent or sleepy, and the dam is destroyed.

Specifications for repairing the break in the dam of the storing reservoir for the Worcester water works, on Lynde brook, in the town of Leicester:—

General description.—The former dam was made of fifty feet width on top, and slopes on each side of two horizontal to one vertical, and forty feet above the base. It was arranged that it could be hereafter built to a level five feet higher, which would have reduced the top width to thirty feet. Although the dam now remaining is of unnecessary width on the top, yet for appearance sake the same outlines will be maintained in the new work of repairs.

The space opened by the breach will be filled with an earthen embankment, in the middle of which will be a puddle wall, and transversely through the bank will be placed three lines of cast iron pipes resting upon and enveloped in a wall of rubble masonry and connected with three cast-off walls of masonry. At the upper end of the pipes, near the foot of the upper slope, will be erected a regulating gate house, and near the foot of the lower slope, a gate well, both of rubble masonry. The upper face of the new embankment will be protected by a slope wall pavement of the same character as that now upon the face of the old dam. The present waste way will be maintained as heretofore, except that the provision for the insertion of flash boards will be removed. The new gate house will be arranged to act also as an additional waste way, discharging at the same level as the present weir.

The important features in the restoration of the dam consist:

First.—Of the removal of the whole of the bottom part of the former "spiling walls."

Second.—Of cutting off six feet in length of the original supply and waste pipes directly under the new puddle wall.

Third.—The founding of the bottom of the new puddle wall into the water-tight original soil by toothing, as shown on the plans, and by jutting vertically and horizontally into the steps with the same toothing. Where the former banks are found to be of good material and to have been carried down into water-tight natural soil, and when such banks have not been disturbed by cracks and slides, they are to be considered as equal to the natural banks, and the puddle wall is to be founded, toothed, and stepped into them, as before mentioned, for the water-tight natural earth.

Fourth.—The new embankment above the center line of the dam will be founded by stepping into toothing and jutting, as described for the puddle wall, but to a less extent; that is, the jutting may be made at intervals of ten feet (transversely to the line of the embankment), and from two to four feet deep and back into the present banks*.

The stone for the gate house and gate well should be of sound, durable, well shaped and large sized stone, such as will make good rubble masonry, and give a good, fair, regular face on the outside and inside of the gate house and well. The whole to be well bonded and laid up compactly in mortar of hydraulic cement. The waste or overflow at the level of top water in the reservoir may be made of the cut stone blocks from the old gate house, and any surplus of such cut stone may be laid for the quoins of the upper portion of the well. The foundation of the gate house, should be made of sound, durable timber and plank, placed at such depth as to be always wet.

Seventh.—The selection of the material should commence at the borrow pit by using the best of the material, breaking up the lumps and throwing aside all stones of more than two inches in diameter. When the earth is deposited alongside of the puddle wall, the same selections and breaking up are to be continued, and again when it is strewn.

The puddle wall should be made as follows: The selected materials deposited (the clay soil on one side and the fine gravel on the other side) along the wall should be distributed by strewing thin layers with the shovel, giving the proper proportion of each by having three men strew the clay and one the gravel, and a fifth man sprinkling with water (being careful to avoid any excess of water), until a depth of six inches is obtained.

When the puddle stuff has been thus prepared and tempered with water, it is to be cut and cross-cut with spades, in cuts of not exceeding one inch in width, taking care that the spades are forced down into the lower course of puddle to thoroughly incorporate the whole mass.

In rainy weather, or when too much water has been used, so as to make the puddle quake like jelly, it must be allowed to remain undisturbed until the excess of water is carried off by absorption and evaporation. Whenever a course of the puddle is finished, and before it can sun-crack, a fresh layer of puddle material must be put on, and whenever the puddle has stood so long as to have lost its moisture, it must be

* Much of the details of the specifications is here omitted.

wet and recut before an upper course is laid on. Carts must not be allowed to pass over the puddle except where planks are laid down.

The puddle wall must be commenced in the lowest place and be carried up in level courses, but the adjacent embankment must always be built up at least six inches higher than the puddle wall.

If necessary (to be avoided if possible) to carry up the puddle higher in one place than in another, it must be done by racking back in steps of not more than six inches depth nor less than two feet tread (four to one).

Eighth.—The upper half of the embankment (made of the selected materials before mentioned) must be built up in level courses of not exceeding four inches thickness, spread evenly by strewing with the shovel and moistening to a proper consistency. The lumps must be broken up fine at the borrow pit, at the dump and when strewn, and a careful selection of the material must be made at each place. The embankment must be commenced at the lowest place, and always be maintained nearly level in both directions, and, if necessary to be built up higher in one place than another, it must be racked back in steps equal to one in four.

The under part of the embankment for ten to fifteen feet high may be made with wheelbarrows; but whether made with carts or barrows each layer must be thoroughly rolled with heavy, grooved rollers before the succeeding one is put on. That portion of the embankment immediately adjoining the puddle wall should be made almost as compact as the puddle wall, and at ten or fifteen feet distant it should taper off in compactness to that of the remainder of the embankment. The lower half of the embankment will be made with the best materials and care, adjacent to the puddle wall, and less care toward the lower slope. The pavement wall on the upper slope has been previously described. It may be laid directly upon the earthen embankment.

Ninth.—The gate house shall be made eight by six on the inside, with walls four feet thick at the bottom, and $2\frac{1}{2}$ feet at the level of top water in the reservoir, and above this there will be arranged a foundation to the house by four brick arches, through which water will flow and wash into the well. The upper house may be of wood or brick, and having access by a small wooden bridge to the top of the embankment. The foundation of the gate house will be eighteen by sixteen feet of pine timbers about eight by twelve inches, covering half the area, and covered with two inch pine plank. The outside wall will be provided with three small waste holes of one foot square, closed with a three inch plank placed on the foundations. The inlet gates will be of cast iron two by three feet, sliding vertically on cast iron frames, three of which will be placed on the upper face of the gate house wall, and protected by a timber and plank frame with wooden screens. In the middle of the inside chamber a strong frame of wood and plank will be placed and let into the side walls and made water-tight. In this frame will be inserted three cast iron gates of the same size, and provided with iron frames the same as those in the front wall. There will also be a frame with a fine wire cloth screen placed above the gate frame.

The face of the wall through which the iron pipes pass into the gate house will be made smooth, so as to allow a wooden gate to be put down in the water and close up each pipe. These three pipes will be separated in the gate house by two vertical wooden partitions. The third or waste pipe will be arranged by means of a floor above to discharge the waste water only into the partition attached to the waste pipe. All of the gates will be provided with the proper apparatus to raise them and to discharge the supply water into each, or to shut it off from each. The lower gate well will be eight by six feet and eight feet deep, covered with trap doors. Each of the pipes will have a stop gate, and the waste gate a curved iron pipe to the discharge culvert. The pipes will be of cast iron of two feet inferior diameter, and $1\frac{1}{4}$ inches thickness of metal connected by leaded joints. Where the pipes pass through the cut-off wall and at the gate house, there will be placed an exterior flange of forty-two inches exterior diameter, which is to be leaded to the exterior of the pipe.

THE CENTENNIAL EXHIBITION.

From "Engineering."

Notwithstanding the somewhat general opinion that the Philadelphia Exhibition would be kept open to the public until the close of November, the doors were shut on the day originally fixed—the tenth—and under very unfavorable conditions of weather the final ceremony of concluding the great show was carried out. It is too early yet to analyze with any accuracy the financial results of the undertaking, but this much may be said, that the number of visitors to the Centennial has far exceeded that of any previous exhibition, and it must be borne in mind that these visitors were composed almost wholly of Americans, and were not made up of all the civilized nations of the world, as has been the case with European exhibitions. The total number of visitors was considerably over 9,000,000, of whom nearly 8,000,000 paid for admision, and the price of entrance, with the exception of a few special days, was fifty-cents., or nearly two shillings, so that the total receipts will have been about £600,000 sterling. This amount, together with the sale of the buildings, amounts paid for concessions, and other sources of revenue, will certainly be quite inadequate to pay the expenses incurred, and a large deficit will doubtless be found to exist, which will have to be made good by the Government and other responsible parties. But that international exhibitions should prove lucrative undertakings is not to be expected; on the contrary, they are almost certain to be attended with heavy losses. If, however, it can be shown that there are direct and indirect benefits arising from an exhibition to the country in which it is held, such benefits must be set against the losses actually incurred, in order to arrive at a fair balance. Thus with the Centennial. It will certainly have cost the United States a large sum, and one of the great indirect advantages attending international exhibitions—that of money spent in the country by foreign visitors—is to a large extent absent. On the other hand, it has thrown into the hands of American exhibitors new and important business connexions, which must bring with them solid and permanent benefit, unshared by other countries, which were practically unrepresented, or rather misrepresented, at Philadelphia. It has been a fitting celebration of the hundreth anniversary of a grand nation, an occasion on which few Americans would stay to count the cost, and it has carried with it those important lessons inseparable from all great displays of industry and art.

But there is another and most important point of view in which to regard the Centennial—and all other international exhibitions—that of the exhibitors. Has it repaid, directly or indirectly, those who have incurred the trouble and expense of sending goods to Philadelphia, of installing them, and representing them during the past season? Generally we should imagine that exhibitors will be repaid. As regards machinery, the show made by foreign countries was so insignificant that the profit or loss was necessarily small. As to American exhibitors we imagine that few will regret the part they have taken at Philadelphia.

We notice in the pages of our contemporary, *The Engineer*, an article (*vide* that journal, page 345, November 17) in which the Centennial and all other exhibitions are sweepingly attacked, and the criticism leveled at the Exhibition just closed, are such as to call for some rejoinder in the names of decency and truth. For some reason or other our contemporary labors under a severe and incurable mania against the United States, its people, and its industry; and writing in a spirit, bred of ignorance and insular prejudice, invents calumnies which it supports by unfounded statements. We have nothing to do here with the broader question of the policy of international exhibitions, but only with the torrent of abuse poured out against the Centennial. We will notice some of these statements in detail. The writer gives exact figures bearing on the charges made to exhibitors for placing their goods in position. They say, "When we find that it cost about £100 to get a small portable engine from England to its place in the Centennial, no less than £17 being charged for taking it out of a packing case," &c. There was only one portable engine from this country, that exhibited by Messrs Davey, Paxman and Co., who also sent a vertical engine and boiler. With the question of freight from England to the Exhibition grounds we have nothing to do, but the charge for unpacking, erecting, and exhibiting lies before us. It is for both engines, and is as follows:

Unpacking, cleaning, painting, and erecting portable and fixed engines, providing timber platforms.....	\$62.75
Signboard................	19.50
Wages for cleaning, and attendant for exhibiting same through the whole term of the exhibition....	160.00
	\$242.25

The engines had suffered in the passage and required considerable cleaning and painting to put them into exhibition order, and the whole charge for this was about £12 for both engines, instead of £17 for one as stated by our contemporary. And this work was done at a time when crowds of exhibitors were eager to unpack their goods, when workmen were scarcely to be obtained, and the almost helpless British Commission did little or nothing to assist their exhibition. In fact, as regards this very exhibit, a notification was sent to the British Commission that the packing cases had been for some days lying unopened, coupled with a request that workmen should be provided for the purpose; but doubtful of the organization at St. George's House, men were at once secured at any cost to work on Saturday night and all day Sunday, so that all was in place on the Monday morning. Some days later a reply was received from the British Commissioner stating that workmen were employed upon the cases; but long before, these men had finished their work and had been paid—by ourselves. To return, however, to *The Engineer:* "On the whole," they say, "we venture to think that the majority of the foreign exhibitors at Philadelphia are exceedingly sorry that they ever went there; and some of them will be yet more sorry when they find that their choicest devices and most exquisite designs are reproduced in the States, and sent to our markets by men who hold, curious as it may seem, that while protection is the best thing in the world, free trade in the ideas of other men is very nearly as good." In other words, that the American national character is so devoid of honesty, that it has invited foreign manufacturers to Philadelphia, that they may be robbed of their ideas, with the result of American copies underselling the originals in foreign markets. It is almost needless to comment on this foolish writing. The above remarks can scarcely apply to machinery, because there was none exhibited from abroad worth copying, and we presume that the "choicest devices and most exquisite designs," refer to fabrics, ceramics, and other art industrial exhibits in the main building.

Now if the writer in *The Engineer* had visited Philadelphia, he would have seen how far behind Europe, America is in its art industries, how many years, it may be even generations, must be passed before pure artistic taste and industrial skill can be developed for the production of the wonderful, though limited results embodied in the English and French exhibits at Philadelphia. The United States is too young, and has been too busy with the stern necessities of life to be able to imitate even faintly European art, and it is to Europe they must look for many years to come, not for devices and designs to steal—the object for which, according to *The Engineer*, manufacturers were invited to the Exhibition —but for manufactured art objects, for which demand in America is rapidly growing, without the least chance of supply except from this side of the Atlantic. What chance is there then that American makers will export their goods to this country, and undersell Minton, Maw, and Doulton, that France need fear for her porcelain or her velvets, that Belgium should tremble for her lace trade, or that the business in Vienna goods should be destroyed by exported American leather work.

The Engineer refers next, in the same narrow-minded spirit, to the difficulties that occured between the Exhibition and our own authorities, and here they have a certain ground for harsh criticism. Exhibitors had great reason to complain of the difficulties placed in their way, of the vexatious obstacles raised by the Customs, and of many other things resulting from bad management. We suppose, however, that these difficulties were interesting to us only so far as our own exhibitors were concerned. And for them we have to thank the British Commissioner. During his first visit to Philadelphia, Mr. Owen had foreseen them all, and had afterwards matured a scheme for smoothing down the obstacles which shortly became so formidable. But Mr. Owen was removed to make place for Colonel Sandford, who was unfortunately in total ignorance of the duties of a Commissioner, because he was without any experience, and, as all the world knows, it was found expedient to recall Mr. Archer when the Exhibition was half over. But from our knowledge we affirm that had Mr. Owen remained in office, none of the above causes of complaint would have remained unremoved.

We now come to another statement made by *The Engineer*, which we almost hesitate to reproduce: "From first to last there was manifested by the Americans a total absence of generous feeling, not only towards strangers, but amongst themselves." Almost every visitor to the United States during the past summer can testify that the statement is devoid of truth. To all those properly accredited the door of hospitality was opened, and no effort, private or public, was spared to welcome visitors. The Reception Committee of the Society of Civil Engineers and the Institution of Mining Engineers carried out the work entrusted to them in an admirable and liberal spirit, and Mr. Bogart, representing the former, and Mr. Neilson, acting for the latter, were unwearied in their efforts to facilitate the movements and comforts of visitors. Throughout the United States works of all kinds were thrown open to foreigners with a willingnes and freedom unknown in any other country, and the excursions planned and carried out were on a scale suitable to the occasion. We will not dwell on this ungracious effort made by *The Engineer* to repay with insult the generosity of Philadelphia during the past season, and we can only hope in all charity, either that the author of the article wrote in entire ignorance, or that he was one of the insignificant few who could not be included within the extended pale of American hospitality. We pass over the allusions to the incompetency of the judges, to the corrupt American press, and to the "oppressive and insulting" system practised on exhibitors, and go on to the last charge made in this article "of the extortion and rapacity of the good people of Philadelphia," which was declared "scandalous" even by the American press. That this accusation is entirely false, all who visited Philadelphia can testify. Doubtless there were plenty of instances of extortion, but none of these cases occurred in the respectable portions of the city. Hotel charges remained unaltered, and they are far cheaper than are known in this country or on the Continent; the prices of the various American restaurants in the Exhibition were all marked by extreme moderation. Carriage hire is always excessively dear in the United States, though it was no dearer last summer than the year before, but other means of communication—tramways and railroads—are notoriously cheap. We can readily imagine an individual accustomed to a tenth-rate mode of living in this country, and seeking similar accomodation in Philadelphia, might fall into bad hands, and pay twice as much there as in London, but at the large hotels the charges made to include all the requirements of the visitors, ranged from 4 dols. to 5 dols. a day. So far from extortion and rapacity, the householders of Philadelphia have earned for themselves a lasting reputation—as compared with London, Paris, and Vienna—for moderation and fair dealing.

We will reproduce a part of the peroration of this article we have been criticising:

"If it could be shown that any great advantage was gained in return for all the trouble taken by exhibitors at Philadelphia we should have consolation, but we cannot indicate a single benefit reaped by the world in general. . . . If the present state of trade in the States is to be regarded as the result of the Centennial, then all we can say is that without the Centennial it must have been so bad as to have almost expired altogether. . . . . What has become of the instruction the world was to receive? Where are the thousands of new ideas, American, and therefore very good [observe the sneer], which the Centennial was to impart? We fear that when men sit down solemnly and add up their new ideas, and put their mental acquisitions together, they will find them very few indeed. The American press is to all intents and purposes silent on the subject; the technical journals one and all practically ignored the contents of the Exhibition. . . . Let our readers run over the pages of this journal for the last six months and see for themselves how much that was good and new could be found in the Machinery Hall by our correspondent (! !). . . . The best American engineering firms sent nothing to Philadelphia, and the result was that the American department, as a whole, represented just what we should expect to find in a country not yet very far advanced in the art of construction."

We will not reply to this quotation in our own words, nor in those of several eminent among our countrymen, who have already expressed their impressions of the Centennial Exhibition and of the country of which it was an exponent, but we will quote from an article written by Mr. Simonin, so well known in the metallurgical world, and recently published in the *Revue des Deux Mondes:*

"It therefore but remains to be inquired into what general teachings the visitor had derived from the great show, especially the European visitor. We may sum up the lesson to the following effect: Thanks to the fertility of her soil, and the facilities of conveyance on land and water, America is now enabled to feed Europe with her grain, flour, and provisions—nay, with live cattle, as she has hitherto already furnished us with cotton. The productiveness of her mines of imcomparable abundance enables her to do without Europe as regards pig and merchant iron, steel, copper, and most of the remaining metals of commerce. She constructs her own machinery and most of the other manufactured goods. But this does not prevent her from shipping to Europe the precious metals which we require for all our transactions, and which the new world turns out as abundantly as the rest of the world put together. As regards coal, to be seen at Philadelphia in blocks of enormous size, America will soon produce of it as much as England—or rather, as much as the rest of the world, her deposits being twenty times the size of those of England.

"This economical lesson seems to us the most striking one we have drawn from a two months' stay at the Exhibition. America will more and more learn to dispense with Europe, while the latter cannot do without America. It is, indeed, a New England which rises beyond the seas, and which already threatens old England in all the markets of the world in the extreme East—Japan, China, perhaps British India, as well as in South America. Although France is not equally as much interested in the struggle that is thus inaugurated as England, yet she is forewarned and begins to feel it. Even our wines and brandies the American vineyards begin to vie with. Only connoisseurs can perceive the difference."

To those indeed who are able to learn anything, the Centennial has taught an all-important lesson. It has brought under our immediate notice a great people, clear-sighted, full of energy and business instincts, owning a vast territory, the natural riches of which throw those of Europe utterly in the shade. Almost every range of climate, every class of soil, probably every mineral product, are met with between the limits of her boundaries. The progress she has made in a hundred years, despite the almost incredible obstacles thrown in her way by nature—and not the least of which have been her "magnificent distances"—affords us a scale by which to measure her advance in another century, an advance which will be incredibly more rapid, when political difficulties which harass the country on every side shall have disappeared. Every year sees the United States not only more independent of Europe, but approaching to the period when she shall become a serious competitor with European manufactures—an important fact which the Centennial ought to have impressed upon all its foreign visitors.

The Engineer remarks that the best

American firms sent nothing to Philadelphia.

What then are the Baldwin Locomotive Works, Sellers, Corliss, and a host of others we could name prominent amongst American manufacturers and exhibitors? True, many conspicuous names were absent, some from the result of accident, like W. B. Bement and Son, others on account of the dullness of trade which has for so long depressed American industry, and who, had the Exhibition taken place a few years earlier or later, would have been represented.

We do not seek for the true motives which have led our contemporary into making criticisms so unfair and so devoid of truth, as those against which we have protested. It is not long since an article denying the right of Americans to rank as inventors, appeared in its columns, and which called forth a rejoinder from a prominent United States Journal, the opening and concluding remarks of which apply equally to the present case: "Such statements as the above, however qualified, can only be characterized as a silly exhibition of 'spleen,' and a journal which has any respect for itself, or for truth, should be ashamed to admit to its columns, much more to print it as editorial opinion. . . . We concede our obligations to the mother country, but when a representative British journal asserts that the world is under no obligations to us for valuable discoveries and inventions, it manifests either dense ignorance or egregions vanity."

ON SOME OF THE CHANGES IN THE PHYSICAL PROPERTIES OF STEEL, PRODUCED BY TEMPERING.

By Prof. A. S. KIMBALL.

From "The American Journal of Science and Arts."

A few interesting, and, to a certain extent, novel results have recently been developed in our laboratory, which I venture to present in their present incomplete form, since the pressure of other duties will postpone, for a few months, further investigations in this direction. Up to the present time the larger number of our experiments have been made upon the behavior of tempered bars under a transverse stress, although a few qualitative trials have been made upon changes in electric conductivity and coefficients of expansion.

I. *The modulus of elasticity decreases as the hardness of the steel increases; in other words the harder the bar, the greater the deflection produced by a given weight.*

Many manuals of practical mechanics give a higher modulus for tempered than for untempered steel. Reuleaux in "Der Constructeur," (page 4,) states that it may be increased fifty per cent. by hardening. Coulomb and Tredgold state that hardening has no influence whatever, while Styffe finds that the modulus is diminished. For our first experiment, five pieces of good tool-steel, each 13″ long, were cut from a half-inch square bar. These were carefully annealed, squared, and polished. No. 1 was laid aside and the others were hardened in cold water in the usual manner; No. 2 was "drawn" on a hot plate to a dark blue; No. 3 to a purple; No. 4 to a straw color; No. 5 was left hard. The modulus of elasticity was then determined by measuring the deflection produced by a weight applied at the middle of the bar. The probable error of the experiments did not exceed one-fifth of one per cent. The experiment was varied in many ways, several qualities of steel and bars of different dimensions were employed with uniform results. In some grades of steel a difference of more than ten per cent. has been found between the modulus of the hardened and that of the annealed bar.

II. *The increase of deflection in a given time is greater the harder the steel.*

It is well known that the deflection of a bar left under stress will increase for a long time. I am not aware, however, that comparative tests of the rate of increase in steel of different tempers have previously been made.

III. *The immediate set increases with the hardness of the steel.*

In the experiments each bar was of course loaded with the same weight which was allowed to act for the same number of minutes.

IV. *A bar recovers from a temporary set with greater rapidity the harder it is.*

The remarkable fluctuations in the line of the bar observed by Prof. Norton, (this Journal, April, 1876,) became more marked and had a wider range as the hardness of the bar increased. In none of the experiments referred to was a permanent set produced, though in some cases forty-eight hours had elapsed before the bar recovered its original line. In a few experiments an attempt was made to determine the approximate hardness of the bars by grinding. The results obtained, however, could not be considered very reliable. A more satisfactory method was found in the determination of the temperatures employed in hardening and drawing, by the specific heat of platinum, or by the use of the pyrometer.

I am indebted to Mr. F. C. Blake for the accuracy with which the experiments referred to in this note, have been conducted.

PREHISTORIC ART AND SCIENCE.*

From "The Architect."

It is a somewhat curious fact that, while all modern writers admit the great antiquity of man, most of them maintain the very recent development of his intellect, and will hardly contemplate the possibility of men equal in mental capacity to ourselves, having existed in prehistoric times. This question is generally assumed to be settled, by such relics as has been preserved of the manufacturers of the olden races, showing a lower and lower state of the arts; by the successive disappearance in olden times of iron, bronze, and pottery; and by the ruder forms of the older flint implements. The weakness of this argument has been well shown by Mr. Albert Mott in his very original but little known presidential address to the Literary and Philosophical Society of Liverpool in 1873. He maintains that "our most distant glimpses of the past are still of a world peopled as now with men both civilized and savage," and, "that we have often entirely misread the past by supposing that the outward signs of civilization must always be the same, and must be such as are found among ourselves." In support of this view he adduces a variety of striking facts and ingenious arguments, a few of which I will briefly summarise. On one of the most remote islands of the Pacific—Easter Island—2,000 miles from South America, 2,000 from the Marquesas, and more than 1,000 from the Gambier Islands, are found hundreds of gigantic stone images, now mostly in ruins, some thirty or forty feet high, while some seem to have been much larger, the crowns on their heads cut out of red stone, being sometimes ten feet in diameter, while even the head and neck of one is said to have been twenty feet high. These once stood erect on extensive stone platforms, yet the island has only an area of about thirty square miles, or considerably less than Jersey. Now as one of the smallest images eight feet high weighs four tons, the largest must weigh over 100 tons, if not much more; and the existence of such vast works implies a large population, abundance of food, and an established government. Yet how could these coexist in a mere speck of land wholly cut off from the rest of the world? Mr. Mott maintains that this necessarily implies the power of regular communication with larger islands or a continent, the arts of navigation, and civilization much higher than now exists in any part of the Pacific. Very similar

* Address of Mr. A. R. Wallace, President of the Section of Biology of the British Association.

remains in other islands scattered widely over the Pacific add weight to this argument. The next example is that of the ancient mounds and earthworks of the North American continent, the bearing of which is even more significant.

Over the greater part of the extensive Mississippi valley four well-marked classes of these earthworks occur. Some are camps, or works of defence, situated on bluffs, promontories, or isolated hills; others are vast enclosures in the plains and lowlands, often of geometric forms, and having attached to them roadways or avenues often miles in length; a third are mounds corresponding to our tumuli, often seventy to ninety feet high, and some of them covering acres of ground, while a fourth group consist of representations of various animals modelled in relief on a gigantic scale, and occurring chiefly in an area somewhat to the northwest of the other classes, in the plains of Wisconsin.

The first class—the camps or fortified enclosures—resemble in general features the ancient camps of our own islands, but far surpass them in extent. Fort Hill, in Ohio, is surrounded by a wall and ditch a mile and a half in length, part of the way cut through solid rock. Artificial reservoirs for water were made within it, when at one extremity, on a more elevated point, a keep is constructed with its separate defences and water-reservoirs. Another, called Clark's work, in the Scioto valley, which seems to have been a fortified town, encloses an area of seventeen acres, the embankments measuring three miles in length, and containing not less than three million cubic feet of earth. This area encloses numerous sacrificial mounds and symmetrical earthworks in which many interesting relics and works of art have been found. The second class—the sacred enclosures—may be compared for extent and arrangement with Avebury or Carnak—but are in some respects even more remarkable. One of these at Newark, Ohio, covers an area of several miles with its connected groups of circles, octagons, squares, ellipses, and avenues, on a grand scale, and formed by embankments from twenty to thirty feet in height. Other similar works occur in different parts of Ohio, and by accurate survey it is found not only that the circles are true, though some of them are one-third of a mile in diameter, but that other figures are truly square, each side being over 1,000 feet long, and what is still more important, the dimensions of some of these geometrical figures in different parts of the country and seventy miles apart, are identical. Now this proves the use, by the builders of these works, of some standard measures of length, while the accuracy of the squares, circles, and, in a less degree, of the octagonal figures—shows a considerable knowledge of rudimentary geometry, and some means of measuring angles. The difficulty of drawing such figures on a large scale is much greater than anyone would imagine who has not tried it, and the accuracy of these is far beyond what is necessary to satisfy the eye. We must therefore impute to these people the wish to make these figures as accurate as possible, and this wish is a greater proof of habitual skill and intellectual advancement than even the ability to draw such figures. If, then, we take into account this ability and this love of geometric truth and further consider the dense population and civil organization implied by the construction of such extensive systematic works, we must allow that these ancient people had reached the earlier stages of a civilization of which no traces existed among the savage tribes who alone occupied the country when first visited by Europeans.

The animal mounds are of comparatively less importance for our present purpose, as they imply a somewhat lower grade of advancement; but the sepulchral and sacrificial mounds exist in vast numbers, and their partial exploration has yielded a quantity of articles and works of art, which throw some further light on the peculiarities of this mysterious people. Most of these mounds contain a large concave hearth or basin of burnt clay, of perfectly symmetrical form, on which are found deposited more or less abundant relics, all bearing traces of the action of fire. We are, therefore, only acquainted with such articles as are practically fireproof, or have accidentally escaped combustion. These consist of bone and copper implements and ornaments, discs and tubes—pearl, shell, and silver beads, more or less injured by fire—ornaments cut in mica, ornamental pottery, and numbers of elaborate carvings in stone, mostly forming pipes for smoking. The metallic articles are all formed by hammering, but the execution is very good; plates of mica are found cut into scrolls and circles; the pottery, of which very few remains have been found, is far superior to that of any of the Indian tribes, since Dr. Wilson is of opinion that it must have been formed on a wheel, as it is often of uniform thickness throughout (sometimes not more than one-sixth of an inch), polished and ornamented with scrolls and figures of birds and flowers in delicate relief.

But the most instructive objects are the sculptured stone pipes, representing not only various easily recognisable animals, but also human heads, so well executed that they appear to be portraits. Among the animals, not only are such native forms as the panther, bear, otto, wolf, beaver, racoon, heron, crow, turtle, frog, rattlesnake, and many others, well represented, but also the manatee, which perhaps then ascended the Mississippi as it now does the Amazon, and the toucan, which could hardly have been obtained nearer than Mexico. The sculptured heads are especially remarkable, because they present to us the features of an intellectual and civilized people. The nose in some is perfectly straight, and neither prominent nor dilated, the mouth is small and the lips thin, the chin and upper lip are short, contrasting with the ponderous jaw of the modern Indian, while the cheek-bones present no marked prominence. Other examples have the nose somewhat projecting at the apex in a manner quite unlike the features of any American indigenes, and, although there are some which show a much coarser face, it is very difficult to see in any of them that close resemblance to the Indian type which these sculptures have been said to exhibit. The few authentic crania from the mounds present corresponding features, being more symmetrical and better developed in the frontal region than those of any American tribes, although somewhat resembling them in the occipital outline; while one was described by its discoverer (Mr. W. Marshall Anderson) as a "beautiful skull worthy of a Greek."

The antiquity of this remarkable race may perhaps not be very great, as compared with the prehistoric man of Europe, although the opinion of some writers on the subject seem affected by that "parsimony of time" on which the late Sir Charles Lyell so often dilated. The mounds are all overgrown with dense forest, and one of the large trees was estimated to be 800 years old, while other observers consider the forest growth to indicate an age of at least 1,000 years. But it is well known that it requires several generations of trees to pass away before the growth on a deserted clearing comes to correspond with that of the surrounding virgin forest, while this forest, once established, may go on growing for an unknown number of thousands of years. The 800 or 1,000 years estimate from the growth of existing vegetation is a minimum which has no bearing whatever on the actual age of these mounds, and we might almost as well attempt to determine the time of the glacial epoch from the age of the pines or oaks which now grow on the moraines. The important thing for us, however, is that when North America was first settled by Europeans, the Indian tribes inhabiting it had no knowledge or tradition of any preceding race of higher civilization than themselves. Yet we find that such a race existed; that they must have been populous and have lived under some established government; while there are signs that they practiced agriculture largely, as indeed they must have done to have supported a population capable of executing such gigantic works in such vast profusion—for it is stated that the mounds and earthworks of various kinds in the state of Ohio alone amount to between eleven and twelve thousand. In their habits, customs, religion, and arts, they differed strikingly from all the Indian tribes; while their love of art and of geometric forms, and their capacity for executing the latter upon so gigantic a scale, render it probable that they were a really civilized people, although the form their civilization took may have been very different from that of later people subject to very different influences, and the inheritors of a longer series of ancestral civilization.

We have here, at all events, a striking

example of the transition, over an extensive country, from comparative civilization to comparative barbarism, the former having left to tradition, and hardly any trace of influence on the latter. As Mr. Mott well remarks:—Nothing can be more striking than the fact that Easter Island and North America both gave the same testimony as to the origin of the savage life found in them, although in all circumstances and surroundings the two cases are so different. If no stone monuments had been constructed in Easter Island, or mounds, containing a few relics saved from fire, in the United States, we might never have suspected the existence of these ancient peoples. He argues, therefore, that it is very easy for the records of an ancient nation's life entirely to perish, or to be hidden from observation. Even the arts of Nineveh and Babylon were unknown only a generation ago, and we have only just discovered the facts about the mound-builders of North America. But other parts of the American continent exhibit parallel phenomena. Recent investigations show that in Mexico, Central America, and Peru, the existing race of Indians has been preceded by a distinct and more civilized race. This is proved by the sculptures of the ruined cities of Central America, by the more ancient terra cottas and paintings of Mexico, and by the oldest portrait pottery of Peru. All alike show markedly non-Indian features, while they often closely resemble modern European types. Ancient crania, too, have been found in all these countries, presenting very different characters from those of any of the modern indigenous races of America.

There is one other striking example of a higher being succeeded by a lower degree of knowledge, which is in danger of being forgotten because it has been made the foundation of theories which seem wild and fantastic, and are probably in great part erroneous. I allude to the Great Pyramid of Egypt, whose form, dimensions, structure, and uses have recently been the subject of elaborate works by Prof. Piazzi Smyth. Now, the admitted facts about this pyramid are so interesting and so apposite to the subject we are considering, that I beg to recall them to your attention. Most of you are aware that this pyramid has been carefully explored and measured by successive Egyptologists, and the dimensions have lately become capable of more accurate determination owing to the discovery of some of the original casing-stones, and the clearing away of the earth from the corners of the foundation, showing the sockets in which the corner-stones fitted. Prof. Smyth devoted many months of work with the best instruments in order to fix the dimensions and angles of all accessible parts of the structure; and he has carefully determined these by a comparison of his own and all previous measures, the best of which agree pretty closely with each other. The results arrived at are:—1. That the pyramid is truly square, the sides being equal and the angles right angles. 2. That the four sockets on which the first stones of the corners rested are truly on the same level. 3. That the direction of the sides are accurately to the four cardinal points. 4. That the vertical height of the pyramid bears the same proportion to its circumference at the base, as the radius of a circle does to its circumference.

Now all these measures, angles, and levels are accurate, not as an ordinary surveyor or builder could make them, but to such a degree as requires the very best modern instruments and all the refinements of geodetical science to discover any error at all. In addition to this we have the wonderful perfection of the workmanship in the interior of the pyramid, the passages and chambers being lined with huge blocks of stone fitted with the utmost accuracy, while every part of the building exhibits the highest structural science. In all these respects this largest pyramid surpasses every other in Egypt. Yet it is universally admitted to be the oldest, and also the oldest historical building in the world. Now these admitted facts about the Great Pyramid are surely remarkable, and worthy of the deepest consideration. They are facts which, in the pregnant words of the late Sir John Herschel, "according to received theories ought not to happen," and which, he tells us, should therefore be kept ever present to our minds, since "they belong to the class of facts which serve as a clew to new discoveries."

According to modern theories, the higher civilization is ever a growth and an outcome from a preceding lower state; and it is inferred that this progress is visible to us throughout all history and in all the material records of human intellect. But here we have a building which marks the very dawn of history—which is the oldest authentic monument of man's genius and skill, and which, instead of being far inferior, is very much superior to all which followed it. Great men are the products of their age and country, and the designers and constructors of this wonderful monument could never have arisen among an unintellectual and half-barbarous people. So perfect a work implies many preceding less perfect works which have disappeared. It marks the culminating point of an ancient civilization, of the early stages of which we have no record whatever.

The three cases to which I have now adverted (and there are many others) seem to require for their satisfactory interpretation a somewhat different view of human progress from that which is now generally accepted. Taken in connection with the great intellectual power of the ancient Greeks—which Mr. Galton believes to have been far above that of the average of any modern nation—and the elevation, at once intellectual and moral, displayed in the writings of Confucius, Zoroaster, and the Vedas, they point to the conclusion that, while in material progress there has been a tolerably steady advance, man's intellectual and moral development reached almost its highest level in a very remote past. The lower, the more animal, but often the more energetic types, have, however, always been far the more numerous; hence such established societies as have here and there arisen under the guidance of higher minds have always been liable to be swept away by the incursions of barbarians. Thus in almost every part of the globe there have been a long succession of partial civilizations, each in turn succeeded by a period of barbarism; and this view seems supported by the occurrence of degraded types of skull along with such "as might have belonged to a philosopher"—at a time when the mammoth and the reindeer inhabited southern France. Nor need we fear that there is not time enough for the rise and decay of so many successive civilizations as this view would imply; for the opinion is now gaining ground among geologists that palœolitic men were really preglacial, and that the great gap—marked alike by a change of physical conditions, and of animal life—which in Europe always separates him from his neolithic successor, was caused by the coming on and passing away of the great ice age. If the views now advanced are correct, many, perhaps most, of our existing savages are the successors of higher races; and their arts, often showing a wonderful similarity in distant continents, may have been derived from a common source among more civilized peoples.

The Sherman Puddling Process.—After the numerous experiments made in England, with altogether negative results, we did not expect to hear more about this process, especially also, as at the meeting of the Société de l'Industrie Minerale, M. Euverte communicated the results of the experiments made with this process, and the conclusion which he arrived at was that it did not appear to have any influence on the quality of the steel, and was not worthy of further consideration by metallurgists. The president of the meeting, M. de Cizancourt, however, protested against these conclusions, declaring that at M. Verdié's Iron Works there had already been more than 1,200 tons of metal containing phosphorus treated by this process with complete success; and at the subsequent meeting of the society, M. E. Verdié read a communication in reply to the paper of M. Euverte, to the effect that the results obtained by using the Sherman process at the Firminy Iron Works proved that even, when the amount of phosphorus present was greater than at Terre-Noire, the steel produced was more carburetted, purer, contained less phosphorus, and was made at a lower price. M. Verdié admitted that the re-agents employed did not consist only of the 30 grammes iodide of potassium, but were alkaline salts in the proportion of two kilogs. per charge, the iodide included, which is, therefore, not exactly the same as specified in Sherman's patent.

TRANSMISSION OF POWER BY WIRE ROPES.*

By ALBERT W. STAHL, Cadet-Engineer, M. E., U. S. N.

I.

Section I.

INTRODUCTION.

It is a noteworthy historical fact, that economy in the generation of power in the motor, and economy in its utilization in the machine, have, in most countries, been far in advance of its economical transmission from the one to the other.

Ever since the steam engine became an established fact in the hands of Watt, inventors have been engaged in making improvements to render it still more efficient. The immense strides taken in advance may be well appreciated by even the most casual comparison of the engine of Watt's time, with one of the powerful and economical engines of the present day.

Not only have such ideas, as the expansion of steam, been developed to a remarkable extent, but even in the smallest details the watchful eye of the mechanic has ever been finding room for improvement.

In the course of invention, the principles upon which the steam engine has been made a practical success have been developed; and during the present century, the chief application of inventive genius has been turned in the direction of improvement in the combination of the parts of the engine itself. There has been no fundamental change in the conception of the necessary parts of the steam engine; but various modifications of the mechanism have been introduced, whereby the power has been economized, or the necessary friction of the parts has been lessened. Influenced by the same spirit which has characterized the scientific advance of this century; by the increasing necessity of more accurate methods; and forced by the industrial competition of the age to consider the importance of economy of time and energy, the improvers of the steam engine have seen that their inventions would be recognized as valuable, only as they attained the same results with increased simplicity of action, with less waste of power in the working of the mechanism, or with a less supply of fuel.

As the Englishman, Watt, in the last century, found the steam engine an imperfect and wasteful arrangement for utilizing only a small portion of the energy of the steam supplied to it, and by his invention of a separate condenser, and then by his method of making the engine double-acting, made it really a steam engine; so in this century the credit is largely due to Americans, such as Allen, Corliss and others, for improvements by which, in the engines known under their respective names, simplicity of construction, together with perfection of economy in working, have been secured.

While, in the department of steam engineering, as well as in the no less important domain of boiler-making, we are thus devoting all our energies to increasing the efficiency of the prime mover, a painful lack of care is manifest in the utilization of the power which we purchased so dearly. Obtaining only a small fraction of the theoretical power, it becomes us to husband it with the greatest care, and to allow it to do its allotted work with the least possible waste in the transmission from the prime mover to the machine.

Years ago there were excellent water-wheels, and by them were driven machines of surprising ingenuity, but the power was conveyed to the machines by means of cumbersome wooden shafts, upon which were wooden drums for the driving belts; gearing, too, made of wood; slow-moving, awkward contrivances for the purpose, and very wasteful of power. In Oliver Evans' "Millwright's Guide," which is recognized as the standard book of his time, we read of wooden shafts, wooden drums, and wooden gearing only.

At a later day, gear wheels were used to transmit the power from the motor to the shaft, while belts or bands were only used to transmit the power from the shafts to the individual machines.

* A graduating thesis at the Stevens Institute of Technology, Hoboken, N. J, June 30th, 1876.

The transmission of power to distances was accomplished by lines of shafting, either laid in ditches underground, or supported on columns high enough not to impede passage beneath the shafts. But even this method was seldom used, except in cases of necessity, owing to its immense first cost.

Although among the most efficient means of transmitting power to short distances, both belting and shafting have the disadvantage, that when the distance becomes great, the intermediate mechanism absorbs an important portion of the power by vibrations, friction, and resistances of every nature; and, for a distance of several hundred feet, we do not get, at one end of the transmission, more than an extremely small fraction of the power applied to the other.

In the case of a mere dead pull, as in working a pump, work is, and has long been, transmitted to great distances; as by the long lines of "draw-rods," used in mining regions to transmit the power of a water-wheel by means of a crank on its main axis, pulling, during half its revolution, against a heavy weight, and thus storing up energy for the return stroke, as the rods, on account of their flexibility, cannot be used to exert a pushing strain. Rotary motion, however, cannot be economically produced in this manner.

Another method, which has been much employed recently, is that known as hydraulic connection; and Armstrong has even perfected apparatus by which water pressure, thus transmitted through, perhaps, miles of pipe, may be converted into rotary motion.

Compressed air has also come largely into use, and there is no doubt that power may be transmitted to great distances by rarefied or compressed air, and may be converted into rotary motion at any desired point. But in the compression of air, heat is generated; and the latter being conducted rapidly away by the sides of the tube, the loss from this source alone becomes very serious. Another disadvantage, incident on both of the last two cases is that unless the area of the tubes is very large compared with the current flowing through them, the loss by friction rises to a large percentage of the power transmitted. The capital to be sunk in pipes, therefore, is very large, and both this expenditure and the waste of power increase directly with the distance. Such were some of the methods employed to transmit power to great distances, before the invention of transmission of power by wire ropes by the Brothers Hirn, of Mulhausen, Switzerland.* These gentlemen have stated the question of the transmission of power in the most general manner, *i. e.* independently of the intensity of the pressure to be transmitted, and of the distance to be passed over; and the solution which they have given to this grand problem is so simple, that the apparatus proposed seems, to the casual observer, to be little else than a more extended application of that commonplace "wrapping connector," the belt and pulley. The principle involved, however, is something entirely different.

Simplicity, always the fundamental characteristic of great inventions, rarely shows itself more clearly than in, as they are called, the telodynamic cables. To a person seeing them in operation, they seem the embodiment of simplicity; nevertheless, the Brothers Hirn have the undisputed honor of inventing them. To satisfy themselves on this point, the International Jury at the Paris Exposition in 1867, made a deep research, and examined the patent registers for many years back, but failed to find anything bearing the least resemblance to the telodynamic cables.

This method of transmitting power depends upon two principles in mechanics:

(1) The dynamic force is measured by the product of the force and the velocity with which it moves;

(2) In mechanical work, power may be exchanged for velocity, and velocity for power.

To illustrate, let us suppose a bar of iron, having a cross sectional area of one inch, to move endlong at the rate of two feet per second. Now, if the resistance overcome is say 5,000 pounds, work will be performed at the rate of 10,000 foot-pounds per second. Now, if we double the velocity of the bar, we will transmit twice the amount of work with the same strain, or the same work may be produced with only half the former strain,

* See "Notice sur la transmission telodynamique, par C. F. Hirn (Colmar, 1862)."

i. e. by a bar having an area of only half a square inch. In a similar manner, if we move the bar with the velocity employed in telodynamic transmission, viz., about eighty feet per second, then, while doing the same amount of work, the strain on the bar will be reduced from 5000 to 125 pounds, and the bar will only need a section of 1-40 square inch. To put an extreme illustration, we might conceive of a speed at which an iron wire, as fine as a human hair, would be able to transmit the same amount of work as the original one-inch bar.

By the application of these simple principles in Hirn's apparatus, the greater part of the force is first converted into velocity, and at the place where the power is required, the velocity is changed back into force.

Section II.

THE DRIVING WHEELS.

The construction of the apparatus is very simple. A tolerably large iron wheel, having a V shaped groove in its rim, is connected with the motor, and driven with a perimetral velocity of from sixty to one hundred feet.

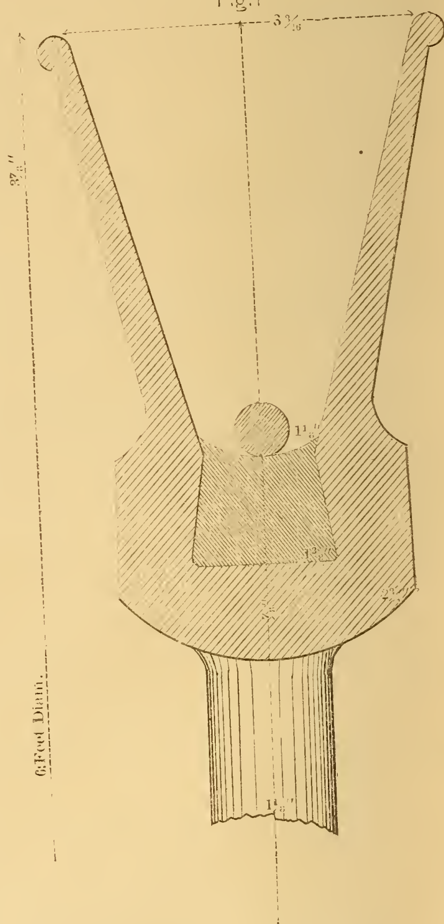
Round this wheel is passed a thin wire rope, which is led away to almost any reasonable distance (the limit being measurable by miles), where it passes over a similar wheel, and then returns as an endless band to the wheel whence it started.

The peripheries of the driving wheels may have an angular velocity as great as possible; the only limit in fact, being that the speed shall not be likely to destroy the wheels by centrifugal force. The speeds which have been actually employed in the examples to which I propose to refer, vary from 25 to 100 feet per second, at the circumference of the pulley.

The wheels themselves are made as light as is consistent with strength, not only for the sake of reducing the inertia of the moving mass, and the friction on the axis to a minimum, but for the equally important object of diminishing the resistance of the air. It can hardly be doubted that abandoning spokes entirely, and making the pulley a plain disc, would improve essentially the performance could such discs be made at once strong enough to fulfill the required function, and light enough not materially to increase the friction.

The wheels have been made of cast iron and steel, and beside their lightness, have but one peculiarity of construction, and that is a highly important one. At the bottom of the acute V shaped groove, going around the circumference, a little trough is formed in which the filling is placed, as shown in Fig. 1.

Fig. 1



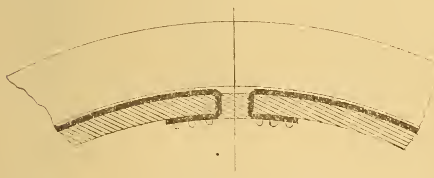
The materials used for this filling are many in number, and will be discussed further on. The rope should always run on a filling of some kind, and not directly on the iron, which would quickly wear it out.

The rope is not tightly stretched over the wheels, but, to all appearances, hangs loosely on the same. But the rope does not slip, as the tension caused by its own weight presses it hard againt the rim of the wheels, if the latter are of proper size. The body of the driving wheel differs very little from that of a belt pulley; and it can always be proportioned as a belt pulley having to transmit the same power with the same velocity. The peculiarity of the wheel lies

Fig. 2

in its rim, as previously explained. In the early experiments on the transmission of power in this manner, the rims were made of wood with a leather belt as filling, (see Figs. 2 and 3.)

Fig. 3



This kind of rim has now gone entirely out of use, and has been replaced by a wheel cast solid with an iron rim, whose edges, in a a single grooved wheel, are inclined at about twenty-five degrees from the vertical, (Figs. 1 and 4). In some instances where the ropes were exposed to a high side wind, the slope has been made as great as 45°, but this a very unusual case.

The angle of 30°, if used in a double grooved wheel, would give an extremely heavy central rib, on which account the sides of the latter are usually made steeper, viz. about 15° from the vertical wheels from about nine feet in diameter up are usually cast in halves and afterward fastened together on the shaft. In order that the centrifugal force may not become dangerous, the perimetral velocity should not exceed 90 to 100 feet per seeond. Velocities up to 90 feet have

Fig. 4

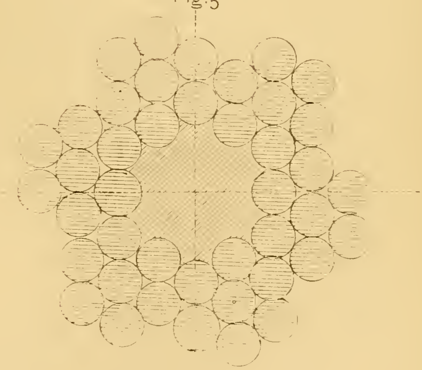
been frequently used. without any prejudical results whatever.

Section III.

THE DRIVING ROPES.

The driving rope usually employed in this country consists of six strands, with seven wires to each strand (see Fig. 5).

Fig. 5



The strands are spun around a hempen center or core, thus obtaining the necessary flexibility.

When wire rope is referred to in this thesis without special qualification, it is to be understood to mean Messrs. J. A. Roebling's Sons' 42 wired round iron wire rope. The diameter of this kind of rope is nine times the diameter of the wire of which it is composed. That is to say, if D = the diameter of the rope, and $d =$ diameter of the wire, then $D = 9d$.

The following table gives the weight, strength, etc., of Messrs. Roebling's

42 WIRED ROPE:

Trade Number.	Diameter in inches.	Circumference in inches.	Weight per foot in pounds.	Ultimate strength in pounds.	Proper tension in pounds.	Price per foot in cents.
25	$\frac{1}{4}$	$\frac{7}{8}$	.125	2060	515	5
24	$\frac{9}{32}$	1	.162	2760	690	7
23	$\frac{5}{16}$	$1\frac{1}{8}$	.189	3300	825	8
22	$\frac{3}{8}$	$1\frac{1}{4}$	.23	4260	1065	9
21	$\frac{7}{16}$	$1\frac{3}{8}$	.3	5660	1415	10
20	$\frac{1}{2}$	$1\frac{5}{8}$	.41	8200	2050	12
19	$\frac{5}{8}$	$1\frac{7}{8}$	.5	11600	2900	14
18	$\frac{11}{16}$	$2\frac{1}{8}$	.686	15200	3800	17
17	$\frac{3}{4}$	$2\frac{3}{8}$	.86	17600	4400	20
16	$\frac{7}{8}$	$2\frac{5}{8}$	1.12	24600	6150	25
15	1	3	1.43	32000	8000	32

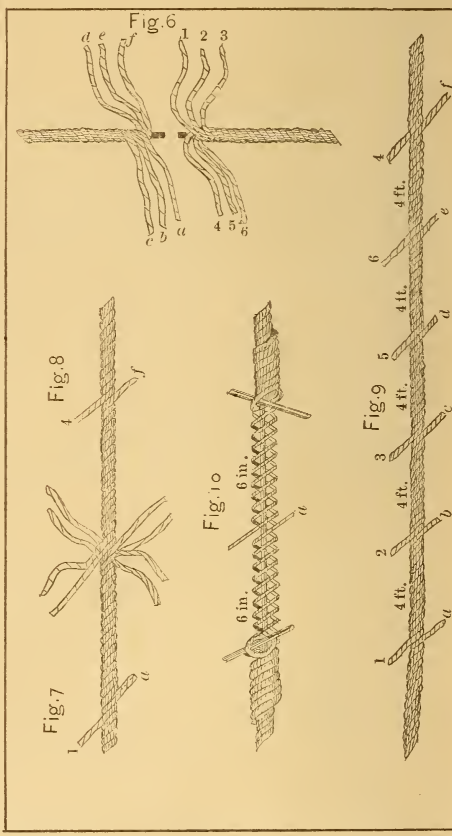
In the manafacture of the rope, the quality of the iron wire must be inspected very carefully, in order to insure durability. The best wire is that made of Swedish iron, uniting great toughness with great tensile strength. Steel wire has not been found well adapted for this work. Particular attention must be paid to getting each wire as long as possible, so as to lessen the number of joints.

In splicing a wire rope, the greatest care must be taken to leave no projecting ends or thick parts in the rope. On this subject, I can do no better than give Messrs. Roebling's directions for making a long splice in an endless running rope of half inch diameter.*

Tools required: One pair of nippers, for cutting off ends of strands; a pair of pliers, to pull through and straighten ends of strands; a point, to open strands; a knife, for cutting the core; and two rope nippers, with sticks to untwist the rope; also a wooden mallet.

First.—Have the two ends taut, with block and fall, until they overlap each other about twenty feet. Next, open the strands of both ends of the rope for a distance of ten feet each; cut off both hemp cores as closely as possible (see Fig. 6), and then bring the open bunches of strands face to face, so that the opposite strands interlock regularly with each other.

Secondly.—Unlay any strand, *a*, and follow up with the strand 1 of the other end, laying it tightly into the open groove left upon unwinding *a*, and making the twist of the strand agree exactly with the lay of the open groove, until all but about six inches of 1 are laid in, and *a* has become twenty feet long. Next cut off *a* within six inches of the rope (see Fig. 7), leaving two short ends, which must be tied temporarily.



Thirdly.—Unlay a strand, 4, of the opposite end, and follow up with the strand, *f*, laying it into the open groove, as before, and treating it precisely as in the first case (see Fig. 8). Next, pursue the same course with *b* and 2, stopping, however, within four feet of the first set; next with *e* and 5; also with *c*, 3 and *d*, 4. We now have the strands all laid into each other's places, with the respect-

* See "Transmission of Power by Wire Ropes," by W. A. Roebling, C. E.

ive ends passing each other at points four feet apart, as shown in Fig. 9.

Fourthly.—These ends must now be secured and disposed of, without increasing the diameter of the rope, in the following manner: Nipper two rope-slings around the wire rope, say six inches on each side of the crossing point of two strands. Insert a stick through the loop and twist them in opposite directions, thus opening the lay of the rope (see Fig. 10). Now cut out the core for six inches on the left and stick the end of 1 under *a*, into the place occupied by the core. Next, cut out the core in the same way on the right, and stick the end of *a* in the place of the core. The ends of the strands must be straightened before they are stuck in.

Now loosen the rope nipper and let the wire rope close. Any slight inequality can be taken out by pounding the rope with a wooden mallet.

Next, shift the rope nippers, and repeat the operations at the other five places.

After the rope has run for a day, the locality of the splice can be no longer detected. There are no ends turned under or sticking out, as in ordinary splices, and the rope is not increased in size, nor appreciably weakened in strength.

I have dwelt so minutely on the process of splicing, because practical experience has demonstrated that a man who can splice a wire rope well, is something of a rarity. Some of the best ship-riggers are utterly non-plussed when a wire rope is presented to them to be spliced; and the splice they produce is usually half again as thick as the rope, and utterly useless for the intended purpose.

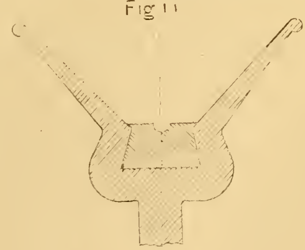
When a rope has been well spliced and kept running, its average life is about three years.

Up to this point, I have been speaking of the common wire ropes, as generally made and used for the purpose of transmitting power, viz. wire ropes with hemp centers, and also those with wire centers. The latter have not given satisfactory results, as they wear out very rapidly. The only advantages to be gained by using a wire center rather than one of hemp, are that the same amount of force may be transmitted with a relatively smaller rope, and that the rope itself stretches less. This latter difficulty can be almost entirely obviated, as will be explained further on; and as the ropes with hemp centers are much more durable, they are now the only ones used. Another disadvantage found in the use of ropes with wire centers, is that the splice must be made nearly twice as long as when hemp is used for the center. This must be done to prevent the two ends of the rope from slipping out, as the co-efficient of friction is not so great between iron and iron, as between iron and hemp.

As in splicing, the wire center is cut off at the splice, and not spliced in, it is free to move in the rope in the direction of least resistance. It consequently happens that the wire center frequently protrudes through the strands of the rope. This may be partly remedied by serving with chord through the center and the outside wires, thus fastening them in their proper relative positions. In a short time, however, the center will again project; we are then compelled to cut off the projecting end, and repeat the operation of serving with cord; which does not by any means improve the durability of the rope. The principal difficulty, the excessive wear of the outer wires, is common to both kinds of ropes. This wear is caused chiefly by the friction of the wire on the sides of the wheel-groove, when the rope, for any reason, runs unsteadily and swings against the sides of the groove. The ropes get flat in places and finally the wires break.

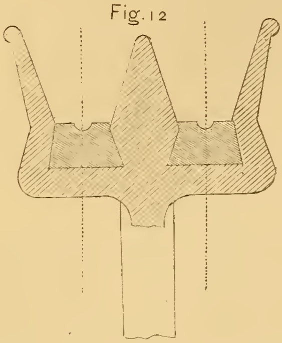
We may keep a transmission in as thorough repair as we will, but we can not prevent, that at times there will be more or less oscillating and swinging of the ropes against the wheel-rim, resulting in the wear above referred to. This evil may be greatly obviated by making

Fig 11



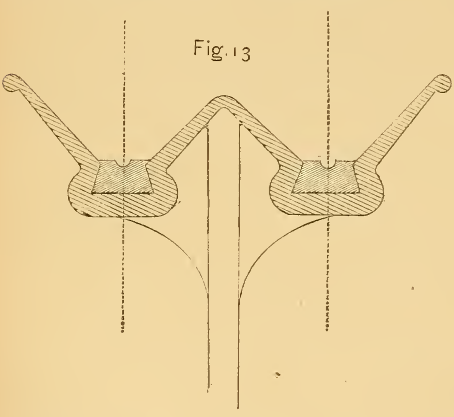
the section of the wheel-rim more of the form shown in Fig. 11. But this is attended with several disadvantages, particularly in the case of double-grooved wheels (compare Figs. 12 and 13).

Fig. 12



This would increase the difficulty and expense of making the wheels, and would have the great disadvantage that the distance between the ropes would be greater, resulting in a considerable side pressure on the bearings of the shafts.

Fig. 13



To prevent the wear of the wires, and thus to make the ropes more durable, has been the object of several inventions; all of which were attempts at surrounding the wires with a flexible and durable covering, protecting the wires, and at the same time not increasing the difficulties of splicing. It was also thought, that if this could be made a practical success, the filling in the wheels might be entirely dispensed with. Instead of the rope running on the soft filling of the wheel, the soft envelop of the rope might run directly on the cast iron rim. Nearly all the experiments in this direction have failed, and it is only very recently that the firm of Martin Stein & Co., Mulhausen, Switzerland, have solved this question. They have for some time been making ropes in which coarse cotton yarn was spun about the separate wires, the latter being then spun into rope. In this way they obtained a soft body between the separate wires, and also a soft envelop for the whole rope, which, when saturated with a special resinous compound, is said to be very durable. This kind of covered rope stretches much less than the common rope. Comparisons made, indicate a stretch of only 06 per cent. It also seems less subject to the variation of weather, being partly protected against sun and rain by the covering. For the same reason, rusting is not likely to occur. If, in connection with these covered ropes, we also employ wheels with leather filling, the adhesive force on the pulleys becomes much greater than in the ordinary ropes; thus allowing the transmission to be worked with much less tension in the ropes. If we desire to get the same cross-sectional area of metal in these ropes as in the common ones, the size of rope required will, of course, be considerably greater, but the rope itself will be much more flexible. In this case, we can, without any harm resulting therefrom, introduce covered wire centres instead of using hemp.

Messrs. Stein & Co. have also been experimenting with hemp as a covering, instead of the expensive cotton yarn, but their experiments are of too recent date to be discussed here.

The price of covered wire ropes is, of course, greater than that of the common ropes. But if they are as durable as the manufacturers claim, *i. e.*, if they may be expected to last about ten years, it is, of course, more true economy to use the more expensive rope. By using these covered ropes, previously well stretched, we may doubtless avoid the various difficulties which have opposed and prevented the more general introduction of the transmission of power by wire-ropes.

Section IV.

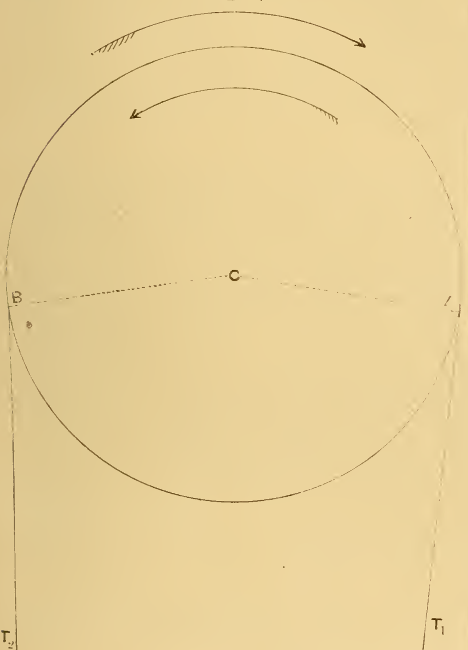
THE TENSION ON THE ROPE.

I shall first present the demonstration of the friction of a simple band, as given in Rankine's "Millwork and Machinery."

A flexible band may be used either to exert an effort or a resistance upon a drum or pulley. In either case, the tangential force, whether effort or resistance, exerted between the band and the pulley, is their mutual friction, caused by and proportional to the normal pressure between them.

In Fig. 14, let C be the axis of a pulley AB, round an arc of which there is wrapped a flexible band, $TABT_2$; let

Fig. 14



the outer arrow represent the direction in which the band slides, or tends to slide, relatively to the pulley, and the inner arrow the direction in which the pulley slides, or tends to slide, relatively to the band. Let T_1, be the tension of the free part of the band at that side *towards* which it tends to draw the pulley, or *from* which the pulley tends to draw it; T_2, the tension of the free part at the other side; T, the tension of the band at any intermediate point of its arc of contact with the pulley; θ, the ratio of the length of that arc to the radius of the pulley; $d\theta$, the ratio of an indefinitely small element of that arc to the radius; $R = T_1 - T_2 =$ the total friction between the band and the pulley; dR, the elementary portion of the friction, due to the elementary arc $d\theta$; f, the coefficient of friction between the materials of the band and pulley. Then it is known that the normal pressure at the elementary arc $d\theta$ is $Td\theta$; T being the mean tension of the band at that elementary arc; consequently the friction on that arc is

$$dR = fT\,d\theta.$$

Now, that friction is also the difference between the tensions of the band at the two ends of the elementary arc; or

$$dT = dR = fT\,d\theta;$$

which equation being integrated throughout the entire arc of contact, gives the following formulae:

$$\left.\begin{aligned} &\text{hyp. log. } \frac{T_1}{T_2} = f\theta;\ T_1 \div T_2 = e^{f\theta} \\ &R_1 = T - T_2 = T_1(1 - e^{-f\theta}) = T_2(e^{f\theta} - 1) \end{aligned}\right\} \quad (1)$$

When a belt connects a pair of pulleys at rest, the tensions of its two sides are equal; and when the pulleys are set in motion, so that one of them drives the other by means of the band, it is found that the advancing side of the belt is exactly as much tightened as the returning side is slackened, so that the mean tension remains unchanged. The ratio which it bears to the force, R, to be transmitted, is given by this formula:

$$\frac{T_1 + T_2}{2R} = \frac{e^{f\theta} + 1}{2(e^{f\theta} - 1)} \quad . \quad . \quad . \quad (2)$$

If the arc of contact between the band and the pulley, expressed in fractions of a turn, be denoted by n, then

$$\theta = 2\pi n;\quad e^{f\theta} = 10^{2.7288 f n} \quad . \quad (3)$$

that is to say, $e^{f\theta}$ is the antilogarithm, or natural number, corresponding to the common logarithm $2.7288 fn$.

The value of the coefficient of friction, f, depends on the state and material of the rubbing surfaces. This coefficient is about 0.25 when wire rope is used running on leather or gutta percha. In wire rope transmission $n = \frac{1}{2}$; inserting this value, and also the value of f, in equation (2), we get :

$$\frac{T_1}{T_2}=2.188\ ;\ \frac{T_1}{R}=1.84;\ \frac{T_1+T_2}{2R}=1.34.$$

In ordinary practice, it is usual to assume

$$T_2=R;\ T_1=2R;\ \frac{T_1+T_2}{2R}=1.5$$

This has been done in the calculations in this thesis. Therefore, if with a wire rope we wish to transmit a certain force P, we must proportion the transverse dimensions of the rope to bear the maximum strain that will come on it. This maximum strain will come on the driving side of the rope and be equal to twice the force transmitted, *i. e.*, equal 2 P.

In all the following calculations, the strength of the hemp core is left entirely out of consideration, as it is only used for the purpose of securing flexibility, and not for strength. If it is an error to leave this out, it is only a slight one, and is on the safe side at that.

Let P=force to be transmittted.

a=total cross-sectional area of wires in rope in square inches.

t=tension in pounds per square inch of cross-sectional area of wires.

Then $ta=2$ P; and $a=\frac{2P}{t}$.

n=the number of wires in the rope $=42$.

d=diameter of each wire ; then

$$n\frac{\pi}{4}d^2=a=\frac{2P}{t}.$$

H.P=number of horse-power to be transmitted.

R=radius of wheel in feet.

N=number of revolutions per minute.

Then, by the proper substitutions, we get:

$$n\frac{\pi}{4}d^2=\frac{2}{t}\times\frac{33000\ H.P.}{2\pi RN}=\frac{33000\ H.P.}{t\pi RN} \quad (4)$$

$$d^2=\frac{132000\ H.P.}{tn\pi^2 RN} \quad \ldots\ldots \quad (5)$$

After substituting for n its value, 42, we get:

$$d=\sqrt{\frac{31.85\ H.P.}{tRN}} \quad \ldots \quad (6)$$

To find the value of d from the preceding equations, we must know at the very outset, what is the proper tension to use in the ropes. The tension in the rope is composed of three parts; viz.: 1st, the tension necessary to transmit the required amount of power with the velocity of the wheel; 2d, the tension produced by the bending of the rope around the wheel, causing the outer fibres of each wire to be extended and strained; 3rd, the tension caused by the centrifugal force.

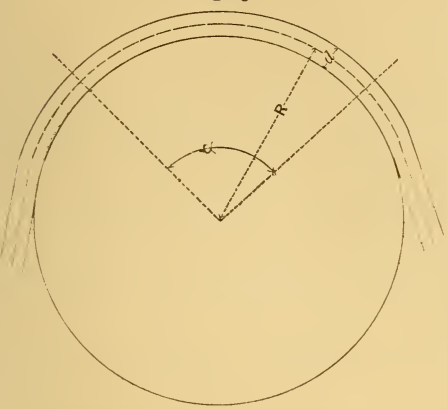
This centrifugal tension, though never amounting to much in ordinary practice, becomes somewhat of an item when a velocity of nearly a mile per minute is employed. It is the sum of these tensions which the rope is called upon to resist.

Determining the proper tension is, of course, equivalent to fixing on a factor of safety. Rankine states that three and a half is a good factor for steady work. Although this may at first sight, seem rather low, it must be borne in mind that the process of wire drawing is a process of testing, so that we are certain of having only the best materials. We may, therefore, safely work with this factor, but for the sake of durability, a somewhat higher factor seems advisable. In this thesis, four (4) has been taken as the factor of safety. To find the tension available for the transmission of power, we must evidently get the difference between the total tension and the sum of the tensions produced by bending and by centrifugal force.

We will, therefore, pass at once to the consideration of the tension caused in the rope, by bending the same around the wheels.

In Figure 15, let R= radius of the wheel, d= diameter of a single wire, and E= modulus of elasticity of wire. Now it is apparent that when the rope is compelled to bend to the curve of the wheel, the outer fibres of each wire will be extended and the inner ones compressed, while the center (the neutral axis) will remain unchanged in length. As the strain varies with the size of the wheel, becoming greater as the wheel is made smaller, and *vice versa* it is of importance to determine what should be the relation between the diameters of the wire and of the wheel. In ordinary practice this ratio ranges between 1,000 and 2,500.

Fig. 15



If in Fig. 15, we consider the arc which subtends the angle ∝, the length of the neutral axis will be $\frac{\pi}{180} R \propto$. But the outermost fiber subtends the same angle with a radius $R + \frac{d}{2}$; therefore, its length must be $\frac{\pi}{180}\left(R+\frac{d}{2}\right)\propto$. The amount by which the outer wire has been extended is evidently the difference between these two lengths; *i. e.*, the extension

$$\lambda=\frac{\pi}{180}\left(R+\frac{d}{2}-R\right)\propto=\frac{\pi}{180}\cdot\frac{d}{2}\propto \quad (7)$$

If t_0=tension produced in the rope by bending, then, from the definition of the modulus of elasticity, "the quotient obtained by dividing the force which produces the displacement by the amount of the extension," we get

$$E=\frac{t_0\frac{\pi}{180}R\propto}{\frac{\pi}{180}\frac{d}{2}\propto}=\frac{t_0 R}{\frac{d}{2}}=\frac{2\,t_0\,R}{d} \quad (8)$$

$$t_0=\frac{E\,d}{2R} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

$$\frac{R}{d}=\frac{E}{2\,t_0} \quad . \; . \; . \; . \; . \; . \; . \quad (10)$$

From these equations the tension may be determined. For the elasticity of iron wire we may take the mean of various experiments; vix.: 28,000,000 lbs. Substituting this value of E_1 and also introducing for d its value $\frac{D}{9}$, we have for the tension per square inch caused by bending

$$t_0=28000000\frac{D}{18R}=1555555\frac{D}{R} \quad . \; . \quad (11)$$

Substituting in equation (11) some of the probable values of the ratio $\frac{D}{R}$, we get the following table:

$\frac{R}{D}$	t_0	$\frac{R}{D}$	t_0
40	38888	120	12963
45	34570	130	11965
50	31111	140	11111
55	28282	150	10730
60	25925	160	9722
65	23930	170	9150
70	22222	180	8642
75	20740	190	8187
80	19444	200	7777
85	18300	210	7407
90	17284	220	7161
95	16374	230	6763
100	15555	240	6481
110	14141	250	6222

This table is somewhat interesting, as it shows clearly the cause of the rapid wear of the ropes when running on small pulleys. When the ratio $\frac{R}{D}$ is large, the tension varies but slightly, with small changes in this ratio; while if the latter is below about 100, the tension increases at a much faster rate than $\frac{R}{D}$ decreases. On the one hand, as the ratio $\frac{R}{D}$ decreases, the wheels become smaller and less expensive; but, on the other hand, we get so great a strain on the ropes that they quickly wear out. We must, therefore, seek to find a point at which the combined resultant economy may be as great as possible. This will be considered further on.

We will now take up the discussion of the centrifugal tension, using the diagram in Fig. 15.

Let R=radius of wheel in feet.

w=weight of the rope per running foot.

v=velocity of the rope in feet per second.

Then the centrifugal force$=\frac{m\, v^2}{R}=\frac{w}{g}\cdot\frac{v^2}{R}$

But the tension in an arc pressed normally by any force p is pR; consequently the *centrifugal tension*

$$t_2=\frac{w}{g}\cdot\frac{v^2 R}{R}=.03106\, wv^2 \quad . \quad . \quad (12)$$

If we wish to express the velocity differently, we may write, when N= number of revolutions per second, $v=2\pi$ R N, $v^2=4\pi^2$ R^2 N^2; introducing this value of v^2, we have

$$t_2=1.226\ R^2\ N^2 w \quad . \quad . \quad . \quad (13)$$

While the rope is passing around the wheel, it is subjected to a tension T, which is equal to the sum of these three separate tensions. But in any given case, we may evidently vary the component tensions at pleasure, provided we keep the total tension T constant.

We have previously (equations (5) and (6)) determined the diameter of the wires in terms of the tension t. But we now wish to introduce the total tension T, into this formula. Bearing in mind that $t=T-t_0-t_2$, and multiplying equation (5) by the value of d, in equation (10), we get

$$d^3=\frac{132000}{\pi^2 n\, E}\cdot\frac{2\, t_0}{T-t_0-t_2}\times\frac{H\ P}{N}$$

$$=\frac{264000\ H.P.}{\pi^2 n\, E\, N}\times\frac{t_0}{t} \quad . \quad . \quad (14)$$

Having now obtained an equation introducing the ratio $\frac{t_0}{t}$, we must know how this is to be determined, i.e., what conditions control the magnitude of t_0 and t with respect to T.

(In all the following calculations, the centrifugal tension t_2 is not taken into consideration, as it only amounts to 250 pounds, even in an extreme case. This is a small quantity compared with the other tensions on the rope, and would lead to a needless complication of formulæ.) These conditions are two in number; 1st, the size of wheel that may conveniently be employed; 2nd, the resulting deflection or sag in the ropes, the latter being again subject to various conditions, such as the available height, etc.

We will now pass to the consideration of the 1st condition; viz.: the size of the wheels. As previously remarked, the value of R varies immensely with changes of t and t_0. The diameter of the wheel, however, is *always* very large, so that it becomes interesting to know under what conditions it assumes its smallest value. The first step is to obtain a perfectly general formula for R. This is done by multiplying equation (14) by the cube of equation (10) which gives as its result

$$R^3=\frac{264000 H.P.}{\pi^2\, n\, N}\cdot\frac{t_0 E}{8t_0^3(T-t_0^3)} \quad . \quad . \quad (15)$$

Differentiating this equation, we get

$$3\, R^2 d\, R=\left(\frac{264000\ H.P\times E}{8\,\pi^2 n\, N}\right)(2Tt_0-3t_0^2)\,dt_0$$

To find the conditions under which R will assume its minimum value, we must place the first differential coefficient equal to zero. Doing this, we get, after transposing and reducing

$$2\, T\, t_0=3\, t_0^2 \quad \therefore \quad t_0=\tfrac{2}{3}\, T \quad . \quad . \quad . \quad . \quad (16)$$

$$t_0=\tfrac{1}{2}\, t \quad . \quad . \quad . \quad . \quad (17)$$

This relation, being independent of the number of wires and of the shape of the rope, will of course hold good for a rope of any size and of any shape of cross-section. This shows the adaptability of this last formula to ropes of flat or rectangular cross-section, which have been used to a limited extent for transmitting power. From this formula, we see that in the case most favorable to small size of wheels, the tension caused by bending is twice as great as the *direct* tensional strain. The minimum value of R is, however, rarely used in practice, for a reason which will be shown presently. It may, however, be remarked here, that with a small working tension t, the deflection or sag of the rope is greater than that with an increased tension; so that in determining the ratio $\frac{t_0}{t}$ we must take into consideration the available height of the wheels above the ground. This point will be considered in the next section.

IRRIGATION IN CALIFORNIA.

By FRANK CARPENTER, C. E.

Written for VAN NOSTRAND'S MAGAZINE.

ONCE a board of honorable, learned, and impartial commissioners* reported that, with a proper system of irrigation, the great Valley of California would in twenty years become the granary of the world. With irrigation, they say, these plains will yield annually thirty bushels of wheat to the acre. Among their statistics they relate how two crops of barley, each forty bushels to the acre, were grown and harvested in the San Joaquin Valley in 245 consecutive days. Such are the favorable conditions of climate and soil that, with irrigation, they predict a probable average of two crops per year. As it is, without irrigation, an average of only two crops in five seasons is realized in the southern part of the valley, and times of famine, which result in the wholesale starvation of stock, are sometimes known. In conclusion, the commissioners report that the Great Valley of California is admirably adapted for irrigation; that the average yearly rainfall over this basin is sufficient to insure good crops annually; that the rainfall in different years is variable, and seasons of drought alternate with seasons of great floods; and that, with a proper system of controlling the waters of precipitation and doling them out to the cultivated fields when needed, regular crops will be assured.

Of the three home questions of vital importance to the people of that great State and little nation, California, the first, as this preface shows, is irrigation, and upon this first the other two hinge more or less directly. With irrigation will come an amicable solution of the second of these home questions, that of Chinese labor, for when the Caucasian freeholders shall become the keepers of the world's granary they will need very many toilers in the field and barn, more indeed than the nominal tide of immigration will introduce for twenty years to come. In overstocked China, the people have long ago learned economical ways of agriculture and the secret of securing great returns of produce from small areas of land, and, coming hither, they will bring with them those habits of frugality and thrift which are the basis of prosperity in the nation and happiness on the hearth, but which the Western land-holders, with farms as large as dukedoms, are inclined to despise. Four acres of land adapted to tillage, by irrigation, will yield as much revenue as four hundred acres of the scant and stunted pasturage now afforded. Therefore, with irrigation become general, the great West will afford homes and refuge to the surplus of all humanity for long to come. Except the mountainous grazing districts of Colorada and Arizona, and the high and forbidden regions around the Black Hills, there are now remaining but few acres of public lands that will, without artificial watering, yield the settler means of life. When these are pre-empted, as they soon will be, our broad domain of desert must be utilized, not as by the shiftless Arab, but as by the industrious Mormon, who has demonstrated that even the sage-brush land, which has hitherto been wronged with the stigma of utter worthlessness, has its virtues of good soil and possibilities of fruitfulness. The alkali flat may be worthless, but the sage-brush barren is not; the presence of this savory herbage is evidence, *prima facie*, that other and better things will grow there.

The great Valley of California is that interior basin at whose bottom lies the lakes of Kern and Tulare. Its available land is equal in area to half of the State of Ohio. It is a lake country, but far different from the lake countries of England, Switzerland, and New York. There is no beauty here, only the slope of low foot-hills subsiding into the plains, the plains running down to the damp bottom-lands, and the marsh sinking into the lake, in whose fringes of tule the water-fowls are at home. By day the sun is hot over these lakes,

*See "Report of the Board of Commissioners on the Irrigation of the San Joaquin, Tulare, and Sacramento Rivers of California; by Lieut. Col. S. B. Alexander and Major George H. Mendell, Corps of Engineers, U. S. A., and Professor George Davidson, U. S. Coast Survey."

breeding malaria, and at night the mosquito rides upon the fog. For this sad state of affairs irrigation is the proposed remedy.

The valley is divided into swamp land, which is too wet for cultivation, and the foot-hills and plains, which are too dry. So it is not the absence of water that retards the settlement and tillage of this vast tract, but its unequal distribution. The body of the water comes from the circumjacent mountains in the rainy season of the year. It rushes across the plains in torrents, fills the lake beds to repletion, and then stagnates and breeds fever during the dry summer. The retention of the water of these cataclysms and its storage upon high land, there to await gradual distribution over the plains and absorption by them, would result in the drying up and reclamation of the marshes, and thus the whole of the valley would become habitable.

But, in the case of the larger streams at least, the establishment of these reservoirs is too vast in nature and too broad in results to be entrusted to individual enterprise, or to any company of individuals less unselfish than the State at large. In irrigation, as elsewhere, the history of chartered companies is too often one of monopoly, forfeited promise, bribery in securing their commission, and subterfuge in fulfilling its requirements. Speculators band together in an incorporated company. They receive a grant of land for digging some canal of magniloquent title. By way of throwing a sop to Cerberus and satisfying the letter of the law, they plow a furrow or two along the proposed route of their public works. Then they disband and divide their subsidy. Or, accomplishing their work, they stand as middlemen between the farmer and the farmer's best friend, the rain, and sell dearly that boon which Heaven intended freely for just and unjust alike. Let the inhabitants of the city of New York fancy that the Croton Aqueduct is a broad river of water instead of a conduit of masonry; that every faucet in their houses has a discharge equal to the flow of an irrigating moat; and that their dependence upon this supply is a matter of prosperity or famine. Then let them suppose that the hands of some one, two, or three of the "kings" and "princes" of that city hold the gates of this main, and they can readily imagine the pitiable condition of the yeomen of the West, if they fall into the hands of the speculators.

The project is too vast to be confided to individuals seeking self-interest. Should the waters of the Sierra Nevada Mountains be leased to a little cabal of capitalists, it will not be long before the shrewdest man of this junto will be preeminent above his fellows; our country will be responsible for the production of another monstrosity, and we shall have our irrigation kings, as we now have bonanza kings, and railroad kings, which phenomenon, in a land which pretends to be averse to the kingly power, will not be consistent. On the other hand, should the rivers be farmed out, one to each company, there would be room for endless conflict, infringement, and litigation; two railways may intersect without jealousy on the part of their owners, but two irrigating ditches, never.

Now, how shall this thing be done? The Board of Commissioners, on account of limited time and means, could do no more than to hint vaguely of some manner of storage in winter and disbursement in summer; the writer begs leave to supplement their report by observations of his own. By way of illustration, let us take the Kern River, one of the principal affluents of this valley, which debouches into the southern portion through a narrow defile in the mountains, which rise some thousands of feet above the floor of the stream. Through these the water has cut a channel so narrow and impassable that there is not room for human travel between the river and its precipitous bluffs, and the stage-road runs perforce by a costly and laborious route high up among the hills. Beyond this cañon is the basin which shall serve as a reservoir. Just above, at the confluence of the forks of the Kern River, there is a valley, some forty or fifty square miles in extent, dyked in on every side by the mountains and their outlying spurs. As a site for a dam this spot is most admirable, and would make an engineer fall into estimates forthwith. Indeed, the body of this weir is already there; it is composed of the mountains themselves, and all that remains for the engineer to do is to wall up the waste-gate of the cañon. If this one little outlet were closed, here would be a cistern with capacity enough to accommodate the gathered product of a thousand rainstorms. True, the back-water would drown out the little villages of Weldon and Kernville, and would flood the mines there; but *n'importe*, grain is better than gold, and this is a project for filling the world's granary.

This would be a prodigious piece of engineering. Such a river, swollen by freshets, is a force before which any ordinary wall of masonry would yield. For this and other reasons it might be unwise to undertake it without previous experiment on a more modest scale. After all, the smaller streams, which come down to the plains at regular and short intervals, can be more profitably utilized than the rivers, which are so large as to be unmanageable and so far between that the conveyance of the water to those fields which lie remote from the source of supply, is a work of great expense. Indeed, this is one of the principal arguments against the wholesale use of a large river, which is to be distributed over a great area. Since the water must be carried by gravitation down a constant and almost imperceptible gradient, the ditches must either wind in and out among the escaloping foot-hills, and around the heads of the valleys, often making many miles of detour in order to accomplish one mile of advance, or else, if the canal be projected in a direct line, frequent aqueduct bridges are necessary. Therefore, it would be well to reserve the four rivers, Sacramento, San Joaquin, Tulare, and Kern, for a few years, and as a last resort, to be used only under the lessons of fullest experiment.

Take, for instance, a creek which has ten miles of route through the mountains, with a proportional breadth of water-shed on either side. This would not be too cumbersome to be managed by a simple individual of means, or, at most, by a co-operative company. As an inventor makes and exhibits a model of the machine which he will afterwards develop to colossal size, so let some party prove, in miniature, the feasibility of irrigation by mountain reservoirs; in making this experiment such person or persons would be doing the world a service, and it would not be rash to promise them handsome returns of pecuniary profit as well.

Let there be taken as a field for this venture, the San Fernando Plain, a basin twelve by twenty miles in expanse, which lies south of the Great Valley. It is now a dry and unprofitable pasturage for sheep, whose frequent dead bodies testify of the insufficiency of their feed, but, with its conformation of gentle slopes, it is admirably adapted for irrigation and cultivation, and, were irrigation possible, this would be a most beautiful realm for a colony. In a dot of green oases on this plain are the gardens of the San Fernando Mission, established here by the Jesuits well-nigh a century ago. In these are tropical fruits and flowers in the rankest profusion and exuberance of growth. There are giant trees of olive and palm, overshadowing an undergrowth of fig and pomegranate, lofty and dense thickets of prickly pear, and tangled meshes of grapevine, while without the walls there is a strip of bottom-land with patches of melons and fields of barley. Again, at the mouth of a cañon not far away we found a squatter's shanty. Two years before, entrapping the stream with a ditch, he had led it away to the field which he had fenced from the sage-brush, growing tall and scraggy around. Eighteen months ago he had planted this orchard. Now the trees were laden so that their tender boughs were in peril. Never before had we seen such abundance of fruit or such precocity in the bearing of it. And yet without the fence was that emblem of desolation, the sage-brush, from which this spot had been reclaimed, barely two years since.

These instances are given as vouchers for the virtues of this land's climate and soil, developed when assisted by irrigation. Although, on account of the narrowness of the belt of water-shed surrounding it, it may never be possible to water the entirety of the San Fernando Plain, yet, with a large portion of it, irrigation is not only possible, but easy. Opening into its eastern border is the Pecoima Cañon, which, at its mouth, is a narrow cleft in the rock, and, at its head, is a broad and spacious sinus. Indeed, this formation, a bowl in the heart of the mountains with an opening which is a fissure, seems to be general throughout this country. If it be true that nature has provided a cure for every one of her defects, then are these opportunities for reservoirs her remedy for the parched plains which lie adjacent, and, having given these hints, she artlessly expects man to do the rest. In the Pecoima Cañon this water gap is so narrow, the walls are so high and perpendicular, and the rock on the mountains overhead is so abundant that it would be a matter of trifling expense to block the cañon with a dam. Yet I daresay that this idea has never once occurred to those people, dons and padres, who have lived so long in this land, and of whom, except some occasional hardy hunter, not one has ever gone farther than to peer into the mouth of this fastness.

It is hard to imagine a finer property than this mountain tract, and a goodly portion of the San Fernando Plains would make. In the scenery of these hills there is grandeur for the artist and on their slopes there is game for the hunter. Right well do we remember how, on that hot summer day, ever as we climbed this cañon we followed the trail of the huge, flat-footed grizzly, which had recently gone before us. Once made, the pond could be stocked with fish and furnished with yachts and canoes, for the amusement and recreation of one's friends of the hectic cheek. Winding stairways among the cliffs would climb to its level, and, from there, farther up to lofty look-outs among the crags, from which to view the farm beneath, with its orange-orchards and vineyards, its green corn and yellow barley. From there, also, the projector of this plantation could watch the progress of his improvements, and, with the redeemed Faust of Goethe, could find the consummation of happiness in seeing

" Green fertile fields where men and herds are found
In comfort dwelling on new tracts of ground."

And in saying with the same—

" Each day report me and correctly note
How grows in length the undertaken moat.
To countless numbers I would furnish land."

There have been two important investigations looking toward the reclamation of the desert land of California, and it is a noticeable fact that these have not been under the auspices of private companies, nor even of so local an agency as the State itself, but have been authorized by the sanction of the General Government. The first of these has already been dwelt upon; the other, yet in progress, aims at the admission of the Colorado River into the Mohave Desert, a great area of utterly waste land, much of it below the level of the sea, whose thirst an ocean would scarcely suffice to appease. Under the instructions of Lieutenant Wheeler, director of the geographical surveys of the War Department, Lieut. Eric Bergeand, an engineer officer, has in the years of 1875 and 1876 led a scientific corps through that region, traversing the desert by various lines of travel, and observing the phenomena of its meteorology, its plant and animal life, and its physical conditions in general. Thence they followed down the banks of the river and along the shores of the Gulf of California, making a careful topographical survey of the plateau which acts as a levee to restrain the water, and seeking some pass of little profile through which it may be diverted by canal.

Along this stream the engineers worked for weeks, measuring the area of its cross-section, and determining, by accurate base-lines on the land and center, side, and sub-floats in the water, the mean rapidity of its current. From these data they compute the volume of its discharge. Knowing this and the meteorological conditions of the desert to the inland, they are able to tell how great an area of this land could be submerged by this volume of water before the absorption of the soil, and the evaporation from the surface of this artificial sea—the evaporation increasing with the square miles of watery surface—would counterbalance the influx from the river, and then the lake would have its maximum area. Knowing this and other meteorological data they make estimates of the climatic influences to be exerted by such a lake and its tendency to make the desert habitable and available for purposes of life and agriculture.

Accompanying this expedition have been experts in natural science, notable among whom is the German chemist and mineralogist, Dr. Oscar Loew, who will report upon the fertilizing properties of the earthy matter held in suspension by the Colorado and other rivers, the nature of the various soils and mineral incrustations found, the influence of extreme aridity on the human system, the kinds and limits of vegetable growth, etc. What the result will be, time and the reports alone can tell, but, whatever the event, these studies will surely be a valuable contribution to the world's store of knowledge, and it is by just such endeavors, even if they are unsuccessful at first, that the future science of irrigation is to be built up.

The third question of weighty interest to California is one of agrarianism. It hinges upon irrigation in so far as irrigation increases the amount of arable land, and with such an increase there comes a natural tendency toward small farms and, what is of importance here, toward definite boundaries between them. Of fertile soil a few acres are enough for the needs of a family, but grazing farms are proverbially large farms, and this has been celebrated as a grazing country ever since those days when its principal exports were hides and tallow. Indeed, its millions of sheep, which, by their close nibbling, take out the grass by the roots, are coming to be recognized as a serious disaster to its prosperity, and if irrigation will transform the sheep-pasture into a wheat-field, it will do a glorious work.

Taken in general, that system of almost unlimited possession known as the *rancho*, and that system of immensity in farming in which men are reckoned like cattle, are not good ones. They smack too much of the feudal order of things. In order to make one grandee there must be a hundred peons, and for every great farmer there are a hundred hirelings, and it is better for the State that a man should be master of forty acres than a servant on forty thousand. However necessary and good this apportionment may be for a new country, it is certainly a fortunate day for that country when these vast tracts are sub-divided among industrious immigrants. The division of Southern California into great ranches, varying in area from 10,000 to 300,000 acres, is a heritage of trouble and a drawback to the State. The original grants, by which these lands first became private property, are faulty papers, shiftlessly designating a boundary line to run from a certain tree, which is now cut down, to a certain stump, now rotted away; and taking advantage of this uncertainty, the avaricious land-holder has too often stretched the perimeter of his estate so as to take in here a spring of water and there a strip of meadow. Hence have arisen quarrels which have developed into law suits, but the mills of litigation grind slowly, and, in the meantime the squatter on this disputed ground has no heart to work. He fears to establish himself a homestead even in this vicinity, apprehensive that he may be declared within forbidden limits and ousted from his improvements after years of toil. To every patient listener they rehearse the piteous tale of ejectment after ejectment and dwell upon the rascality and perjury of these ranchmen, who are not Mexican dons, as of yore, but American speculators.

Under these circumstances, they say, what heart can we have to build ourselves houses that are homes, and invest our little money in these farms of doubtful title, which the next session of court may wrest from us; we can only "skin" the land while we stay, and be ready to move at any moment. For this reason, finished country houses are very scarce in this land, and the merest shanties are made to serve for residence. For instance, there was the Spaniard, Goleo Farollte, who guided us so well from Santa Paula into the mountains. This man was an old settler of twenty years standing. He owned hundreds of horses, and of cattle, more than he knew. Still better, he owned the respect of all who knew him, for he was an honest and honorable man. Though rich in more respects than one, yet the house where he dwelt was but a scanty hovel, too small for his children to grow in. Still he could not build other, he said, until the almost interminable law suit should be over and he should be left undisturbed in his possession.

So goes the strife; who are right, let time and the jurymen tell, but this I know, that the observer from abroad must have his sympathies well subdued, or he will surely find himself wishing that the spirit of the agrarian dispensation might be introduced into the land laws of Southern California.

IMPORTANCE OF HYDRO-GEOLOGICAL SURVEYS FROM A SANITARY POINT OF VIEW.*

By BALDWIN LATHAM, C. E., M. Inst. C. E., F. G. S., F. M. S., &c.

From "The Engineer."

It is now generally admitted that all supplies of water are due to rainfall; a portion of the rain percolates into the earth and forms a subterranean store, which is almost in universal requisition to supply the wants of man. The amount of rain that percolates into the earth depends, in a great measure, upon the geological character and physical outline of the district. The experiments of Dalton, Dickinson, Evans, Greaves, Lawes and Gilbert, show that the percolation varies in different years, and at different periods of each year, the replenishment of the store of underground water usually taking place in the winter months, and the exhaustion of the store in the summer and autumn months. The amount of water stored in the earth, other things being proportional, is equal to the volume of the strata, or the thickness of the beds. There are, however, other matters which affect the quantity of water percolating, such as the extent and nature of the outcrop of the strata receiving the rainfall, the volume of the strata, the lithological character, and the free communication between different parts. Professor Prestwich states, in his work upon the "Water-bearing Strata of London," that "Oolites, limestones, some sandstones, &c., instead of holding definite quantities of water in proportion to their masses, will hold indefinite quantities proportional only to the number and magnitude of the crevices and fissures by which they are traversed, and the water so held will not pass indifferently in any direction, but must follow the irregular and uncertain channels presented by those joints and fissures. The late Very Reverend Dr. Buckland pointed out that the water held in store by the earth did not, as a rule, maintain a horizontal level, but that its surface possessed a considerable fall in particular directions corresponding to the points of discharge of springs.

The fall of the water line having been established, it is not difficult to perceive that, where a considerable difference in surface level of subterranean water is discernible, this water must be moving in the direction of its outfall or natural vent. Water level, therefore, in subterranean strata, means the line drawn from the highest point at which it accumulates to the lowest or point of vent. Most geological strata in a natural state may be considered to be full to the level of the sea; beyond this there is an extensive store of water above this level, rising, in many districts, to a considerable altitude. The inclined surface of this water is the measure of resistance to the movement of the water in its passage, or, in other words, it is the measure of the element of friction and molecular attraction which interferes with the free discharge of the water, so that the water is retained in its subterranean reservoirs and but slowly delivered from them, the rapidity of the discharge of this underground water depending on the porosity of the strata, and the size and extent of the ducts which convey it to its natural point of outfall.

These subterranean currents, although hidden from view, obey the same laws with reference to their flow as streams which move on the surface of the earth; elevations, faults, and artificial works may interfere with their flow. The late Very Rev. Dr. Buckland observed that the elevation of the subterranean water between the town of Watford and the highest spring that issued from the neighboring chalk hills was 300 ft. in a distance of fourteen miles. In 1842 the Rev. James Clutterbuck made a communication to the Institution of Civil Engineers, in which it was stated that the replenishment of the chalk north of London usually occurred between December and March, and that the water accumulates in the chalk proportionally as the point of observation is removed from the river or natural vent of the water, and that the water in the chalk when full falls be-

* British Association.

tween April and November, the variation in level in the upper chalk exceeding fifty feet. In 1843 he further stated, at a meeting of the Institution of Civil Engineers, in reference to falls of water in the chalk: "It is then shown that a line drawn from a point three miles south of the Colne, at the level of that river, or 170 feet above Trinity high-water mark, at mean tide level in the Thames below London Bridge (a dip of 180 feet in fourteen miles, or an average inclination of thirteen feet per mile), cut the water level at the point whence it is drawn at Hendon Union Workhouse, and at Cricklewood between that place and Kilburn, whence it may be inferred that up to this point there is no apparent trace of a depression of level caused by the exhaustion of water under London." In a communication from Mr. John Evans, F.R.S., to the Institution of Civil Engineers in 1861, it is stated:—"The inclination at which water would stand in the middle chalk north of London was, under ordinary circumstances, at least thirteen feet six inches to the mile, which was proved by the streams generally running at about that slope. It was evident that if water could pass through the chalk with that inclination it would find its way by some underground passage instead of by the streams. In its lower beds the chalk was of a nature to increase the friction, and it would be found that in the neighborhood of Berkhampstead the water stood at an inclination of about nineteen feet six inches to the mile, and in some parts of Kent and elsewhere at as much as forty feet to the mile." Professor Prestwich, in his work on "The Water-bearing Strata of London," states that the fall of water in the tertiary beds is about five feet per mile at Garrett, and four feet per mile at Waltham Abbey, while the well of Grenille, in the lower greensand, indicated a fall of two feet per mile.

The results of a hydro-geological survey, made by the author, of the neighborhood south of Croydon, show that there is considerable variation in the fall of the subterranean water.

In all cases the fall of subterranean water decreases as the exhaustion of the strata proceeds.

A hydro-geological survey of East Dereham, Norfolk, made by the author when prospecting for the site of waterworks, shows that in the case of wells sunk in the boulder clay overlying the chalk, the level of the surface of the subterranean water varies in the town from two feet per mile in the flat table land to 100 feet per mile in the valleys. The movement of the subterranean water appears to have been known even in classic times. We find it recorded that in the war between Cæsar and Pompey, when at Petra, Pompey suffered very much. They could get no water on the rock, and when he attempted to sink wells Cæsar so perverted the water-courses that the wells gave no water. Cæsar tells us that he even dammed up the streams, making little lakes to hold it, so that it should not trickle down in its underground courses to the comfort of his enemies.

No question can be of more importance, from a sanitary point of view, than that of the supply of wholesome water. It is known that water does not in itself change in character, but it becomes noxious as it is made the vehicle for conveying injurious matter. Hippocrates appears to have been aware of the importance of pure water, and, moreover, of the best places for its selection, or as it has been stated, "upon the aspect of its sources as well as upon its elevation." Mr. Simon, of the Medical Department of the Privy Council, in his report of 1869, stated that "the doctrine in general terms, that a vast influence is exercised over the health of communities by the quality of the water which they consume, is one which, as far back in literature as any reference to such questions could be expected to exist, may be seen to have universal medical consent in its favor; and, during long ages of history, the common instincts of mankind were even purer and stronger than undeveloped science. Of the many invaluable additions and improvements which medical knowledge has received within the last quarter of a century, scarcely any can, in my opinion, be compared for present practical importance to the discoveries which have given scientific exactitude to parts of the above stated general doctrine, and have enabled us definitely to connect the epidemic spread of bowel infections in this country with the existence of certain faults of water supply.

Not only is it now certain that the faulty public water supply of a town may be the essential cause of the most terrible epidemic outbreaks of cholera, typhoid fever, dysentery, and other allied disorders, but even doubts are widely entertained whether these diseases, or some of them, can possibly attain general prevalence in a town except where the faulty water supply develops them." Such may be said to be the testimony of one of the highest medical authorities in this country. Authorities in other countries have likewise drawn attention to the importance of the purity of water supplies, and, moreover, Professor Pettenkofer has shown that there are in some cases certain definite relations between epidemics of enteric fever and cholera and the state of the level of the ground water.

In the year 1870 the author was called upon by the Croydon Local Board to inquire into the state of health of the inhabitants of a cluster of sixty-nine houses situated in the hamlet of Wellington, near to the Sewage Irrigation Works of the Croydon Local Board. The author then reported that in all the houses in which the cesspools were placed on the north of the habitations they had been, so far as was known to the present inhabitants, entirely free from any zymotic disease, whilst those with cesspools located in other aspects the tenants had suffered at different times from various kinds of zymotic disease. At that time the author attributed it to the effect of the prevailing winds wafting any miasms in the direction of these houses, but more careful investigation shows, with respect to these houses, that the current of underground water is from south-east to north-west, and that the well and the cesspool are invariably on opposite sides of the house. In all cases in which the well is located, as respects the fall of the subterranean water, above the cesspool, the house has been invariably healthy, and in every case in which the cesspool is located above the water supply that house has, so long as the water from the well was in use, never been long free from enteric fever; in fact, the use of water from most of the wells so located has been prohibited by the medical gentlemen in attendance on the occupants of these houses.

During the past year an outbreak of enteric fever having occurred in the parish of Coulsden, near to Caterham Junction, south of Croydon, and knowing that the inhabitants of these houses had previously suffered from outbreaks of this fever, the author found that in the case of all the occupants of all the houses affected with the disease the cesspools were situated on the subterranean current above the well, so that polluting matter must naturally be carried by the movement of the water into the well.

Numerous other cases in different parts of the country have also been brought to the author's attention which clearly show that, in many instances, if attention had been paid to the subterranean movement of the water, and the sites of the wells and cesspools exchanged, much disease and death would, in all probability, have been prevented. The periods at which epidemics of cholera, enteric fever, dysentery, and diarrhœa occur, show that usually they have reference to the low state of the springs, when the movement of the water is least active, and therefore when the concentration of impurities is the greatest. It has been very clearly shown that the movements of underground water do influence the health of populations. In the "Transactions" of this Association for 1837, it is mentioned in a paper by Mr. Urquhart, that the plague at Constantinople is shown to have particularly affected districts in which the burial grounds stood above the places afflicted. In the Seventh Report of the State Board of Health of Massachusetts, an example of drainage from a cemetery affecting health is given:—"That mentioned by Pietra Santa, of the villages of Rolendella and Bollita, in Italy. The cemeteries of these villages were at the summit of a wooded hill, at a considerable distance from the houses. The spring from which water was obtained was at the foot of the hill, and ultimately the water became highly contaminated. A severe epidemic which recently visited these villages was ascribed to the use of this impure water. A similar case occurred during the past year at Barbary, as an incident of the plague which has recently visited that country. The people of a certain village lived in excavations in rocks, getting their water supply from wells into which water had run from the cemetery where bodies were covered only a foot deep with gravel. Those only who drank this impure water were attacked with plague." So important is this matter considered in some countries, as to the contamination of drinking water by proximity to cemeteries, that regulations have been laid down as to the distance from which they shall be from inhabited districts. In Italy no well is allowed to be sunk within one hundred yards of any cemetery, and double this distance is required in France and Austria. This is called the "protective distance," but has, in some cases, been thought to be too small.

The Hygienic Council at Brussels in 1852 decided that a distance of 400 yards was protective, but even this distance has been sometimes conceived to be inadequate. In Prussia no cemetery is allowed within 500 paces of any dwelling. At Lausen, on the railway between Basel and Olter, the morbific matter of disease was carried a distance of two miles through a hill to the village on the opposite side, as recorded in the Fifteenth Annual Report of the Army Medical Officer. This latter village, however, was below the point at which the infectious matter was carried, but on the direct line of flow of the subterranean water, as was subsequently proved by experiment. The safe distance with regard to the influence of cemeteries and other sources of contamination on the water of wells will depend upon the position of the point of pollution with reference to the water supply. A well situated a few yards above a cemetery with regard to the flow of the water may be perfectly safe, whereas one located below a cemetery, on the direct line of flow, present experience shows that no reasonable distance can be said to be a safe limit. So long since as 1827, it was shown by Professor Liebig that nitrates existed in twelve wells in the town of Giessen, but none was found in wells two or three hundred yards from the town. The direction of the flow was not given in this case. Examination of waters both within and without a town, or waters flowing to or from a town, give a marked difference in a chemical point of view. In the "Transactions" of this Association for 1851, Dr. R. A. Smith says with regard to the impurity of well water, "The number of cases of sickness from these causes is, I am inclined to think, greater than is believed." This expression had reference more to impurities that might be supposed to pass into the wells from their unprotected state, than being due to the position of the well itself, in reference to the causes of pollution; but the fact is recorded by a careful observer that well water, under certain conditions, does not minister to the health of the persons using it. The baneful effects of storing or nurturing excrementitious matter in receptacles in close continguity to our water supplies are patent, at times, to the most casual observer, but the public, and many professed sanitary reformers, are not thoroughly alive to the magnitude of the evils due to this cause.

A careful hydro-geological survey will show the directions in which subterranean water is moving, and may enable the residents of country houses to locate their well for procuring a supply of water, and the cesspools in such a position as to avoid impurities passing from the cesspool to the well, but as a general rule, no consideration is given to this matter, and it is usually seen that the cesspool is so located that it leads to the pollution of the water supply; or the underground current, after receiving its load of impurities, slowly passes under the dwelling house, and as the soil under the house from being protected from the weather will invariably be found to be cracked and fissured to a considerable depth, impure aëration takes place from a polluted ground atmosphere. It is a singular fact that all epidemic outbreaks of enteric fever, whether directly ascribed to the influence of water or to milk, in every case of the water used had been procured from wells.

It was shown with reference to the outbreaks of cholera in the metropolis that the relative intensity with which this disease attacked various parts, that nearly the whole force of the blow was expended on the lowest levels. Moreover, from the reports published by Dr. Laycock in the first volume of the Report of the Commission on Towns, with respect to York it is shown that in the sweating sickness of 1550 and 1551, and again in the plague of 1604, that these epidemics exhibited the same relation with regard to season of the year as exhibited in modern times by other epidemics.

In conducting a hydro-geological survey it should be thoroughly borne in mind that, as a rule, water underground follows the natural inclination of the surface of the district, but there are exceptions to this rule. There are also circumstances which may modify the flow of water, such, for example, as the abstraction of a large volume of water at a particular point by pumping from a well, which well would become the center for a drainage area extending, in all probability, to a considerable distance from the well, or in some flat districts the elevation of the water line of a river, in time of flood, may reverse the direction of flow, for some distance, of the under-ground water, unless, as is the case in some wells which are known to be tidal, the volume of water flowing to the river is very large. It is scarcely possible in a town where there are so many points for pollution to so locate a surface-well as not to be affected by some of them. The use of the water from surface-wells located within a town ought, therefore, to be prohibited being used for domestic purposes. In villages the wells should be located outside and above the village in reference to the flow of subterranean water. The same remark applies to the well for procuring a supply of water to a private house.

It is rather singular that while measures are being adopted for the prevention of the pollution of streams flowing on the surface, and which, by the way, have never been traced to be the cause of disease, no one has thought of the great evils that have resulted, and will result, from the pollution of the underground sources of water supply. The object of the author has been to direct attention to this all-important subject, and to point out, in cases where the use of cesspools is unavoidable, that there are ways in which they may be introduced without detriment to the health of the person using the water, which possibly can only be procured from a local well.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The Society sent out in December the following to all the members, calling for their vote.

Special Ballot.—By order of the Board of Direction, the following, presented at the Eighth Annual Convention and then referred to the Board, is, without comment, submitted to vote by letter ballot ;—

"*Resolved*, that the American Society of Civil Engineers will further by all legitimate means, the adoption of the Metric Standards in the Office of Weights and Measures of Washington, as the sole authorized standards of weights and measures in the United States; that the chair appoint a committee of five to report to the Society a form of memorial to Congress, in furtherance of the object expressed; and that the foregoing be submitted to the Society and voted on by letter ballot."

Shall a committee be appointed for the purpose set forth ?

Boston Society of Civil Engineers.—A valuable paper on the Ventilation of the Hoosac Tunnel, was lately presented to this Society by Thomas Doane C. E. We shall soon publish it.

IRON AND STEEL NOTES.

Rusting of Iron.—In vol. 218 of *Dingler's Polytechnic Journal*, pp. 70-79, will be found the results of a series of experiments made by A. Wagner, on the production of rust upon slips of iron exposed to water containing various salts in solution, and in the presence of air free from carbonic acid, and of air containing that gas at various temperatures, and also in sealed tubes from which the air had previously been expelled.

We must refer to the original paper for details, but may here mention that, whilst pure water in presence of air caused the iron to rust, this was found to occur more rapidly if carbonic acid was present at the same time, and the production of rust was materially increased by the presence of the chlorides of magnesium, ammonium, sodium, potassium, barium, and calcium, the first-mentioned being the most active in this respect.

Iron immersed in river water concentrated by evaporation was found to rust more slowly than when in distilled water, and whilst the presence of oils or fats greatly diminished the rapidity of rusting, it was found that alkalies prevented it entirely. A solution of chloride of magnesium, in the absence of air, attacked iron at the temperature of boiling water, but solutions of the chloride of sodium, potassium, barium, or calcium, were not found to do so.

Determination of Phosphorus in Iron and Steel.—At the February meeting of the American Institute of Mining Engineers a paper was read on this subject by Mr. Andrew A. Blair, of the Watertown Arsenal, in Massachusetts, and although the process described by him is not new, it has some features in its details which, we think, will render its re-production acceptable to chemists engaged in similar investigations. Five or ten grammes of the borings are treated with strong nitric acid, adding from time to time a few drops of hydrochloric acid, and applying heat until the solution is complete. The solution is then evaporated on a water bath to a syrupy consistency, twenty to forty cubic centm. of hydrochloric acid added, the beaker covered and heated until all action has ceased, when the cover is washed down and the solution evaporated to dryness. This operation is repeated, and when the residue is dry it is re-dissolved in hydrochloric acid, and when the solution appears to be complete, an equal volume of water is added to it, and the solution boiled for a few minutes to convert any basic or pyrophosphate of iron that may have been formed by too high a temperature into the orthophosphate. The solution is then diluted and filtered, the filter worked with dilute hydrochloric acid, and then with hot water, and the filtrate diluted to about 750 cubic centm. To this is added a sufficient quantity of acid sulphite of ammonium, to reduce all the ferric to ferrous salt. This reduction is facilitated by rendering the solution as neutral as is possible by ammonia, even adding as much, after the sulphite has been added, to render the solution turbid. This slight precipitate may be re-dissolved by adding a few drops of hydrochloric acid; and when the reduction is complete, and the solution has been heated to boiling, an excess of hydrochloric acid is added to decompose any excess of the sulphite, and the whole boiled until every trace of sulphurous acid has been driven off. Although an excess of acid in the first place interferes with the perfect reduction of the ferric salt, when this is complete, the excess prevents subsequent oxidation and facilitates driving off the sulphurous acid. The solution should be kept boiling briskly, the beaker being covered by a large watch glass and stirred frequently but cautiously, as the solution has a tendency to boil over when suddenly agitated. Once the smell of sulphurous acid is gone, the beaker should be put into cold water, and the water renewed until the solution is cold. Dilute ammonia is then added until a slight precipitate of green protoxide of iron remains undissolved after stirring. A decided excess of acetic acid is then added, which re-dissolves the protoxide of iron, whilst the ferric phosphate remains insoluble. A few drops of ferric chloride are now added, and the solution heated to boiling. The precipitate should now have a decided reddish color, owing to excess of ferric oxide thrown down with the phosphate, this indicating that all the phosphoric acid present has been precipitated as ferric phosphate. The cooling of the solution previous to the precipitation of the phosphate is to prevent the formation of a hard scaly oxide of iron during the subsequent boiling. The solution, when heated to boiling, is filtered as rapidly as possible through a close filter, the solution being kept boiling all the time, the beaker is washed out, and the precipitate on the filter, several times with boiling water. The filtrate should be quite clear, which is always the case when sufficient excess of acetic acid has been used. When clear it never contains any phosphoric acid, but if cloudy during filtration, owing to too little acetic acid or to so much ammonium, it always contains phosphoric acid. This is due to the fact that, although ferric phosphate is insoluble in acetic acid, it is very soluble in ferric acetate, and also in sulphurous acid, should the latter not have been entirely boiled off. The more neutral the solution the greater its tendency to oxidation, which accounts for the favorable action when an excess of acetic acid is added. The precipitate on the filter, and adhering to the sides of the beaker, is dissolved in strong hydrochloric acid, the filter well washed with hot water, and if the solution exceeds forty or fifty cubic centm. in bulk, it is evaporated down; sufficient citric acid is then added, to prevent the precipitation of the ferric oxide on the subsequent addition of ammonia, then magnesia mixture, and finally an excess of ammonia; the entire solution should not exceed seventy-five cubic centm. in bulk. It is cooled in ice water, and when perfectly cold is stirred carefully until the ammonia, magnesia, and phosphate, is seen to be precipitated; then, after standing in ice water for some time longer, it is stirred vigorously several times and allowed to stand at least from eighteen to twenty-four hours before filtering. When filtered, without washing, the precipitate still remaining in the beaker, and that on the filter, is dissolved in hot dilute hydrochloric acid, a little citric acid added, and the ammonia magnesian phosphate again precipitated by adding excess of ammonia, using the same precautions as before; filtered after standing twelve to twenty-four hours, washed with very dilute ammonia water, and then dried, ignited, and weighed as magnesian pyrophosphate.

With regard to the determination of phosphoric acid by the molybdate of ammonia process. it has been recommended by both Rose, Frezenius, and others, that all silica should be removed from the solution previous to the precipitation. Mr. E. H. Jenkins, however, in a paper in the March number of the *American Journal of Science*, entitled "The Effect of Silicic Acid upon the Estimation of Phosphoric Acid by Ammonium Molybdate," has made an experimental enquiry into the question, and comes to the conclusion that "in no ordinary case" is a previous separation of silicic acid necessary to ensure all desired accuracy in the estimation of phosphoric acid by the molybdic method.

RAILWAY NOTES.

CANADA, on the 30th of June, 1875, had 4,484 miles of railway in operation, which has now probably been increased to 4,500 or more. In 1850 the amount was only fifty-one miles; in 1855 it had jumped to 1,218; in the next ten years it was nearly doubled, reaching 2,231, and in the next decade to 1875, it had again nearly doubled, rising to 4,484 miles—a rate of increase just about the same as that of the United States. The number of inhabitants in Canada per railroad mile is about twice as great as in the United States, while the number of square miles of area per railroad mile—153—is nearly four times as great; so that there is a much greater field for railroad operations in the Dominion, if only the extent of territory be considered, than in the States. Owing to the inhospitable climate of much of Upper Canada, however, those regions will not be fully developed until the temperate zone is peopled, but the Canadian Government and people are showing commendable enterprise in railroad building, and a few years will find a large additional area opened to cultivation and civilization.

A Swiss inventor envelopes the driving axle of locomotives in coils of insulated copper wire, and by the passage of an electric current converts the wheels into powerful magnets, with increased adhesion to the rails. This is charming, with the exception that numerous patents have already been taken for the same thing, and that it will not and could not work with any practical effect. The Swiss gentleman referred to has brought out something at once new and good.

The mean duration of rails of Bessemer steel is, according to careful experiments in Germany, about sixteen years. On the other hand, ten years of trial at Oberhausen on an experimental section of the line between Cologne and Minden has shown that the renewals during the period of trial were 76.7 per cent. of the rails of iron of fine grain, 63.3 of these of cementation steel, 33.3 per cent. of those of puddled steel, and 3.4 per cent. Bessemer steel.—*Annales Industrielles.*

English and American Locomotives.—It has already been announced in our pages that the Midland Railway Company have entered into contracts for the purchase of twenty passenger locomotives, at a cost of £2,500 each. The *Railway Age,* an influential American contemporary, commenting on this statement, says:—"American locomotive builders would be glad to furnish a good class of engines for $8,000 to $9,000 each, and we presume would build as good ones as those required by the Midland for less than $12,000. They are already sending their locomotives to several foreign countries. Perhaps England will become a customer also." This is an assertion which deserves attention. In this country it would be impossible to obtain engines at all comparable with those used on the Midland Railway for £1.800; but it is a noteworthy fact that this has been said to be the cost of Mr. Webb's latest locomotives built at Crewe. We do not vouch for the accuracy of the statement. It appears to be proved that American locomotives are cheaper than English locomotives, and that they do as much work in their way, and do it as well; but the working conditions are so various that there is nothing certain on the subject. We wish some one of our great railway companies would buy an American locomotive, and try for themselves whether there really is anything peculiarly advantageous in a much-vaunted system of construction. If there is, we fancy as good locomotives could be built on American patterns at this side as on the other side of the Atlantic. If there is not, then a good deal of boasting would probably be silenced, at least for a time.

Some interesting observations on the injurious effects of snow on steel rails are communicated from an Austrian line of railway, the Kaiser Ferdinand northern line. A portion of this line, about eight English miles in length, between Floridsdorf and Wagram, is very open, and often blocked with snow in winter time. The obstacle is generally surmounted by strewing sand over the rails in front of the driving wheels to increase their bite, and putting on extra steam. This portion of the line in question has a double line of metals, formed partly of Bessemer steel rails and partly of light Martin steel rails weighing about 30.50 kilogrammes per running meter. Now, the slipping of the wheels frequently caused heating of the tires and rails, which are suddenly cooled again by the low temperature of the air or the falling snow. This, in itself, must be injurious to the molecular construction of the metal. But, beside, the increased friction causes a certain amount of abrasion of the upper surface of the rails at the spots where the stoppages have occurred. Examinations proved that these abraded portions varied in length from two to nine English inches in length, $\frac{1}{12}$ inch to $\frac{1}{4}$ inch in depth, and extended over the whole breadth of the rail. A train in passing over the depressions so caused necessarily experiences a certain shock, and it is reasonable to suppose that the concussion thereby communicated to the rail will be most felt when the ground beneath is frozen hard, so that the natural elasticity of the rail has no room to play. In three instances rails so worn snapped asunder suddenly at the abraded portion, although no flaw or defect in the metal could be detected. This led to the removal of all abraded rails from this section of the line, amounting to twenty-eight lengths of Martin steel rails, and ten lengths of Bessemer rails. No similar case of fracture is known to have occurred in the iron or puddled steel rails previously in use, although the amount of abrasion they underwent must have been at least as great. The inference is that the improved rails of Bessemer and other steel, their superior strength notwithstanding, are less capable of withstanding concussion than the older rails, and consequently whenever they are used increased vigilance is requisite to prevent accidents in the winter time.

Mr. J. B. Fell lately read a paper "On Experiments made at the Camp of Aldershot with a New Form of Military Field Railway for Rapid Construction in Time of War." He explained that he had the permission of the Secretary of State for War for reading his paper, which gave the results of experiments which the Royal Engineer Committee at Chatham had carried out at the camp at Aldershot, of which Captain Luard, C. E., and himself had charge. The experimental railway, he said, consisted of a succession of timber viaducts, which supplied the place of earthworks, culverts and bridges, and which, when the materials have been prepared, could be erected with great rapidity. The conditions the committee desired to have fulfilled in the trials were that an engine not exceeding six tons weight should take a train of thirty tons up an incline of one in fifty and travel at an average speed of ten miles and a maximum of twenty miles an hour. The wagons were required to carry a load of three tons dead weight each, and from 300 to 500 cubic feet of bulky articles, such as tents, hay and commissariat stores. A seven ton seige-gun was to be carried on two wagons, and it was to be shown to be practicable to construct one mile of railway per day, over such ground as was selected by the committee at Aldershot, by the labor of 500 men. The experimental railway was one mile in length, gauge eighteen inches. Steepest gradient one in fifty, the sharpest curve three chains radius, and one of the viaducts was 660 feet in length, and twenty-four feet in height. The structure was of a simple form, and consisted of two beams which were bolted to a kind of trestle-work supports which were sunk to a depth of twelve inches and firmly fixed in the ground. The rails being laid on the beams completed the railway, for the construction of which no other than military labor was required. The experiments occupied at intervals a period of twelve months, and the committee came to the conclusion that the result of the trial had proved that the above-named conditions had been complied with in every particular, and even exceeded. It had been shown that a single line of field railway, constructed on the plan employed at Aldershot, would be capable of carrying ammunition and commissariat stores sufficient for the supply of an army of 100,000 men; that a double line and day and night service would be capable of supplying an army of 300,000 men; that a single line of railway could be made over ground like that at Aldershot at the rate of two miles a day by 500 men; and that if it should ever be required it would be possible to construct a field railway at a speed at which 100,000 men could march. An ordinary transport ship accompanying an expedition would carry the materials and rolling stock for twelve miles of railway of two feet six inches or three feet gauge, to be worked by engines of ten tons weight and wagons carrying six tons each, and the railway could be made for about £5,000 per mile, the cost of erecting included.

ENGINEERING STRUCTURES.

The Channel Tunnel.—The British Society of Engineers publishes the following details of the preliminary works for the tunnel under the channel. The year 1875 was profitably employed. The outlay amounted to 61,000 francs, the half of which, or 30,500 francs, had been expended in geological researches at the end of December, as shown in the report presented at the first general meeting on the 15th of March, 1875, by M. Lavalley. The result of the first year's labors is contained in four reports, which were then distributed, and which describe the bases on which the studies are founded. This year the surveys have continued on a larger scale. In 1875, 1,522 soundings were taken, of which 753 brought up specimens from the bottom of the sea. The engineers had at their service the Pearl, a small steam tug with insufficient appliances, and with which they worked between August 10 and September 21, during which time they could only leave the port of Boulogne twenty times. This year the soundings have been effected on the English side with a large vessel fitted with a crane and better provided. The work commenced at the beginning of July, and the vessel is stationed at Dover, which port it can enter or leave at all hours. Greater progress in the formation of the company has, however, been made in France than in England. The 2,000,000 francs required for the preliminary surveys have not yet been raised.

A portion of a tunnel which is being built under Cavendish Court, Houndsditch, connecting the Metropolitan Railway from Bishopsgate to Aldgate, gave way lately, burying beneath the ruins a number of workmen, and carrying with it a horse and cart and the driver. Four men were taken out dead, and five so dreadfully hurt that small hopes are given of their ultimate recovery.

The Tall Chimney at Glasgow.—There are few chimneys which have any peculiar historic interest, but an exception is presented in one built at Glasgow by Mr. Joseph Townsend, and attached to that gentleman's chemical works. This chimney is to its neighbors what Mount Blanc is to the rest of the Alps—a giant among pigmies. The foundation of this chimney was laid in March, 1857, and on the 6th of October, 1859, the coping was added at the top, at a height of 468 feet from the foundation, and 454 feet from the level of the ground.

At the foundation the outside diameter is 50 feet, and at the surface it has diminished to 32 feet, while at the top of the coping the diameter is 12 feet 8 inches. On the 9th of September, 1859, and while the chimney was still unfinished, and therefore before the mortar was dry, a storm occurred which resulted in swinging the chimney out of the perpendicular to the extent of five feet at the top. This accident, though perhaps directly due to the storm, had its origin in a neglect in the building process. Proper allowance had not been made for the contraction of the mortar used in setting the bricks, and as a consequence a certain number of planks were under a great pressure, being arched in the centre. Suddenly one of these at one side gave way in the oscillation caused by the storm, and with the unequal pressure the chimney was then forced from the perpendicular to the extent above stated. That the accident occurred in this way Mr. Joseph Townsend ascertained by personal observation. For a time some fear was entertained that the whole chimney would come down, but on the 21st of the same month measures were taken to prevent this, and by the 1st of October, the whole was restored to the original upright form. This was effected by sawing the chimney on the side nearest to an imaginary straight line. The following figures give the intervals at which cuttings were made:

1	....	128 feet from the top.		
2	....	49 feet below 1		
3	....	22	"	2
4	....	15	"	3
5	....	12	"	4
6	....	19	"	5
7	....	20	"	6
8	....	13	"	7
9	....	20	"	8
10	....	30	"	9
11	....	40	"	10
12	....	40	"	11
13	....	41	"	12
				449 feet.

When the chimney was only two years old, it was struck by lightning, and a fire ensued, the composition gas-tubing being melted at a distance of 100 feet from the gas meter, though this latter was situated twenty feet from the chimney. To understand how this happened, it is necessary to state a few additional facts. The chimney was provided with an electric conductor on one side, and a coil which united with the conductor near the ground, where together they were bound to an iron rod and passed through a well of water, situated near the side of the foundation, seven feet square and two feet deep, and thence down about eight feet into the earth. Now, into this well comes the drainage of the works, and, further, the discharge pipe from a water-closet, and it was found, on investigation, that although the pipe actually discharging into the well was of stoneware, yet, further back, it was in connection with one of cast iron. This latter pipe, being midway between the conductor and the gas composition tubing, must have served as a vehicle for the electricity, which must then have completed its circuit by the gas pipe, which was thereby melted, and, the gas escaping, caused the fire.

To prevent the recurrence of such an accident the cast iron pipe was removed and one of stoneware substituted. All now went well till three years ago, when the chimney was again struck by lightning at 150 feet from the top, thirty bricks being then dashed out. Again an examination was instituted and it was found that a separation had been effected between the conductor and the rod of iron with which it was bound where it passed through the well at the bottom. This separation had probably happened before the accident occurred and so possibly caused it. A new rod ten feet long and passing eight feet into the earth was now substituted for binding the conductor and coil together, and the whole was well tallowed to prevent oxidation, and was finally enclosed in a wooden box, of which the side of the chimney made the fourth. But a year ago the chimney was once more struck by lightning on the opposite side to that which was last attacked, that is, on the side along which descends the conducting rod. On this occasion a part of the coping stone was knocked off and Mr. Joseph Townsend impressed with the necessity of making some material change in the whole system of protection from lightning, is now providing the chimney with an apparatus which it is to be desired will fulfil its object.

This arrangement may be described in a few words. On the top of the coping-stone are fixed four equidistant rods about three inches wide and one inch thick; these terminate in stars or arrow-heads, and above them in the centre ascends a rod twenty feet long and higher than the rest, terminating in a double arrow-head. All these are properly connected with bands of iron, and are placed in good communication with the electric conductor and coils.

As may be readily imagined, there is some difficulty and not a little danger in raising such masses of iron to the height of 470 feet, but still more difficult and dangerous is it to construct the apparatus at the top, and fix it and bolt it together as is required. For besides the exposure of the workman to the gases from the chimney, the atmosphere is often highly electric at that height, and freedom from sudden wind cannot be ensured. The construction is nevertheless approaching completion, and the whole of it has been done by one man, Mr. R. Hall. He is, perhaps, the only man who would undertake such work, and yet he does it with scarcely a sense of danger, and certainly with none of fear. It seems as easy to him to walk about and work on the coping stone as it is to many of us to walk about on the ground.

In concluding this sketch, which we hope may prove of some interest to manufacturers who have tall chimneys attached to their works, we would merely point out that not a little success of the working of an electric conductor, depends upon the way in which it is sought to distribute the electric current over the earth. It is not sufficient simply to pass the rod down so many feet into the ground, but it should terminate preferably in a plate or sheet of iron, so as to present a good surface for diffusion.

ORDNANCE AND NAVAL.

NOVELTY IN MARINE ARCHITECTURE.—The Canadians find the ice which for nearly six months every year blocks the St. Lawrence, a great barrier to direct European trade. How to overcome it is a problem their shipbuilders have been endeavoring to solve, and there has recently been launched at Quebec, a vessel designed for making winter voyages down the St. Lawrence to Prince Edward Island. If she is successful other and larger vessels on the same model may be built for European trade. She is named the *Northern Light*, and will be fitted for sea by November. She is sheathed with one of the hardest of woods—greenheart—and plated with iron. Her construction is such that there can be no right-angle pressure from ice on any part of the hull. The draught of water aft is seventeen feet, and the screw is so placed that there will be at all times at least five feet of water above the upper blades, so as to prevent contact with ice. Her engines will be of 700 nominal horse power.—*Iron.*

THE SPEZIA EXPERIMENTS.—We understand that Mr. Nathaniel Barnaby, C.B., Director of Naval Construction to the Royal Navy, is about to proceed to Spezia to examine the results of the recent experiments with the 100-ton Armstrong gun, upon the iron and steel plated targets, as it is felt by the authorities that it may be desirable for us to adopt steel, instead of iron, for our armor plating, and there is even some talk of replacing the iron armour plates of the Inflexible with steel, if Mr. Barnaby should report as favorably concerning that material as the accounts already received non-officially lead the Admiralty to expect. The enormons and startling improvements both in artillery and armor plating, which are daily being made, most conclusively, we think, show the wisdom of the policy which has been adopted in our navy, and which we have consistently upheld, viz., that we should advance by slow degrees, and when we think we have got the type of the fighting line of battle-ship, to build only one or two experimental vessels, instead of a large fleet, as we may be certain that before the year is out some fresh improvement is sure to be made which will necessitate a new design. The Inflexible has been built to carry four 81-ton guns, and already the construction of a 160 ton gun, the size of which would prevent its being carried in the turrets of the Inflexible, is talked of. We are pleased that Mr. Barnaby is going to Spezia, but we doubt that steel is better than iron.

THE NAVY DEPARTMENT of Turkey is one of the eight ministerial departments of the Divan. Turkey has now seven ironclad frigates. The two largest ironclads are the sister ships Mésondivé and Mendonhijé, launched in 1874. They are 9,000 tons displacement, have a main deck battery of twelve 18-ton guns, projectile 400 lb. The forward and after ports of the casement are cut at an angle, so as to answer for bow and stern chases. The casemate is of twelve inch iron, and the hull is protected by twelve inch belt, the deck forward and abaft the casemate being shell proof. The spur is of unusual strength and below water. Two six ton guns on forecastle, fire directly ahead, one gun abaft of same calibre, fires directly astern. On spar deck are six 20-pounders, probably for saluting—total 21 guns. The Azizieh, 900, 16 guns; the Orkanieh, 900, 16 guns; the Mahmoudieh, 900, 16 guns; the Osmadieh, 900, 16 guns; and the Athor-Terfik, 750, 8 guns. There are also five ironclad corvettes carrying four or five guns each, and the two monitors, Hejzie-Rahman and the Loufan Djelil, carrying two 150-pounders each, and two light guns. The twin-screw ironclads Aoni Illah (help of God) and Muin Taffer (aid to victory) are sister ships of 1,400 tons armor, five and a half inch. Four 12-ton rifle Armstrong guns, 250-pounders, are mounted in a central battery, so arranged as to admit being fired ahead or astern. These two vessels are said to possess very high rate of speed.

MORE MONSTER GUNS.—If the advice of the Woolwich authorities had been taken long ago, we should, observes the *Daily News*, probably not now have to deplore the possession of a fleet which, however imposing in appearance and really powerful in offensive armament, is yet defensively so weak that the armor-plating of our most formidable ironclad can be readily pierced by the 100-ton gun recently built for the Italian Government, a weapon which does not by any means represent the limit of power that can be reached by modern artillery. Messrs. Armstrong & Co., for the Italians, and Messrs. Krupp, for the German navy, have probably facilities at their factories for turning out guns of the highest calibre yet reached sufficient to arm, by the beginning of next summer, all the ironclads at present in existence in those countries, whereas the building of a ship to resist the force of their projectiles would be a labor of some four years. The very common-sense advice of the heads of the Factory Department at Woolwich was that the greatest possible power of any single piece of artillery should be approximately ascertained before large numbers of costly ironclads were built which a great increase of velocity and energy in heavy projectiles might soon render comparatively useless. In this opinion, expressed ten years ago, they clearly anticipated the day of such monster guns as the "Woolwich Infant" of eighty tons, and the latest production of the Elswick firm, which weighs something over 100 tons. Instead of this, however, public and private yards in various parts of England were busily employed in building numerous ironclads, the thickness of the armor-plating of which was calculated on purely theoretical bases, so far as the penetrative power of the artillery that might be brought against them in the future was concerned. The result is that we have not a ship in the English navy capable of withstanding a direct hit from the great Armstrong gun, or even from the 80-ton Fraser gun, which will soon be tried for pentration at Shoeburyness, and which will, in the opinion of our most experienced artillerists, be found capable of doing all that the Italian 100-ton gun has yet accomplished. It is some satisfaction, however, to know that in this respect other countries are at a still greater disadvantage, while there is every reason to believe that Woolwich is quite prepared to hold its own against the world in the matter of heavy ordnance, and to begin building, at a week's notice, Fraser guns of greater calibre and power than the highest triumphs of Elswick or Essen.

Thanks to the exhaustive trials at Shoeburyness and Woolwich, the results, and even every detail of which have been open to the world, data have been furnished whereby one of those firms at least, has been enabled to steal a march on our own gun factories. But the advantage is happily only temporary, for Woolwich is now in a better position to build guns of 200 tons than it was to undertake those of 80 tons when the order for manufacturing an experimental weapon of the latter weight was first issued. Designs for a gun 164 tons have been for some time in the hands of the War Department, but it is now almost certain that this immense calibre will be surpassed, and that the pet piece of ordnance for the English navy of the immediate future will be a Fraser gun, weighing about 200 tons, 50 feet in length, having a bore of twenty inches, and throwing, with a powder charge of something like 800 lb., a projectile weighing from 3900 lb. to 4,000 lb., or considerably over a ton and a half. As we have said, Woolwich is quite prepared to undertake the construction of such a weapon, and the only obstable in the way is the difficulty of providing working space in a turret for such a monster. The question of weight is not so material as that of length; and it was the opinion of Admiral Boyd (Director of Navy Artillery) and Mr. Barnaby (the chief Constructor) that 164 tons represented the extreme limit for turret-guns in such ironclads as the *Inflexible*. The hydraulic system of loading devised by Mr. Rendle, of Sir William Armstrong's firm, has, however, considerably modified the conditions, and the hydraulic checks by which recoil is reduced to a minimum, have so far contributed to economy of space, that it may now be found possible to work a gun of fifty feet in length within turrets only slightly larger than those of the *Inflexible*. If not, this length, and consequently the power and accuracy of the weapon, will have to be somewhat diminished, though it is thought that the 800 lb. powder-charge and the 4,000 lb. projectile might still be used. At all events, the factories at Woolwich are quite equal to any demands that might be made on them to build guns of either 164 tons or 200 tons, and the choice between these two now rests with the Admiralty authorities and their constructors.—*Iron.*

BOOK NOTICES.

REPORT ON THE JETTY SYSTEM AS APPLIED TO THE CHANNEL OF ENTRANCE TO CUMBERLAND SOUND. By Maj.-Gen. Q. A. GILLMORE. New York: D. Van Nostrand.

This is an important contribution to the discussion which so largely engages the attention of engineers, at the present time.

Gen. Gillmore's success as an engineer, and as a writer on engineering practice, will ensure a wide reading to this brief report. Like the author's previous performances in scientific essays and reports, the present one is free from any waste words, is equally free from theoretical mathematical investigation, with its double integrals, but is full of practical science.

Three folding plates illustrate the report.

REPORT ON THE TRANSPORTATION ROUTE ALONG THE WISCONSIN AND FOX RIVERS By Maj.-Gen GOUVERNEUR K. WARREN. Washington: Government Printing Office.

This report is a valuable addition to the literature bearing on the Hydraulics of our American Rivers. The survey of which this is the final report was made by direction of the government, with special reference to the improvement of water-transportation between the Mississippi River and Lake Michigan. To engineers the Report will be chiefly valuable as a scientific treatise on the improvement of shallow rivers of considerable slope, small volume, and movable bed.

The Report is divided into five chapters, of which the first three are chiefly historical, the fourth is descriptive of the rivers, their hydrology, and the adjacent territory as shown by the survey; the fifth is on "the methods of improving navigation," and is entitled to the most respectful attention of the engineering profession.

Ten folding plates illustrate the report.

A CONCISE HISTORY OF THE IRON MANUFACTURE OF THE AMERICAN COLONIES TO THE REVOLUTIONARY WAR, AND OF PENNSYLVANIA FROM THEN TO THE PRESENT TIME. By JOHN B. PEARSE, A. M. Philadelphia: Allen, Lane & Scott. For sale by D. Van Nostrand. Price $2 00

The above title sufficiently explains the scope of this work. No pains have been spared apparently to make this history complete.

It is a record of the changes in the iron trade, and of the successive improvements in the iron manufacture.

A large authentic map contains the geography of iron mines, and iron works of Pennsylvania.

THE INSURANCE CYCLOPEDIA. By CORNELIUS WALFORD, F. L. A., F. S. S. London: Charles & Edwin Layton. For sale by D. Van Nostrand. Price $9.00 per vol.

This work in six large royal octavo volumes, contains, first, a complete dictionary of the definitions of all terms, relating to insurance in all its branches; secondly, A Biographical Summary, of the lives of all contributed in any way to the development of the theory and practice of Insurance; thirdly, A Bibliographical Repertory, of all works on the subject of Insurance, and its associated sciences; fourthly, An Historical Treasury, of events connected with Insurance Companies; fifthly, A detailed account of the rise and progress of Insurance in Europe and America.

Three only of the six volumes, are as yet published.

PRACTICAL TUNNELING. By FREDERICK WALTER SIMMS, C. E. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $12.00

This is a third edition of a well known and standard work, revised and extended by D. Kinnear Clark, C. E. In addition to the matter included in the former editions, the present volume includes an elaborate elucidation of the latest developments of tunneling practice.

The systems of driving tunnels known on the Continent, as the English and the Belgian systems, based on the bottom heading, and the top heading respectively, are fully explained. A discussion of the common casualties in tunneling occupies considerable space, as does also some details of experiences in tunneling in clay, marl, coal, and hard rock,

The St. Gothard Tunnel receives a full share of attention.

The whole work is executed in a style not excelled by any scientific volume in any country.

THE FLEETS OF THE WORLD. By Com. FOXHALL A. PARKER. New York: D. Van Nostrand.

Commodore Foxhall A. Parker, of the U. S. navy, whose contributions to what may be termed "Nautical" literature, in the past have been of exceeding use and value, both scientifically and practically, has written a volume entitled "The Fleets of the World—The Galley Period," which can hardly fail, gaining its deserts, to have a very wide circulation and extensive reading. Commodore Parker's other works, such as "Fleet Tactics under Steam," "Squadron Tactics under Steam," "The Howitzer Afloat," and "The Howitzer Ashore," have became standards in our naval instruction schools, and have the highest place as authorities in our navy. We have been permitted to examine most of the advance sheets of Com. Parker's latest work, and have no hesitation in pronouncing it one of the most interesting character historically, and as a continuous chronicle of sea-conflicts and marine operations in early days, it is marvelously entertaining as well as instructive. The volume deals with the "Galley Period" of China, of Egypt, of Phœnicia, of the Greeks and Persians, the Danes, and in short of all peoples, a portion of whose community engaged in sea-faring in the age which has now long passed away. The transcript shows the author to be a diligent scholar and student himself; one who has read and collated, gathering from great masses, the material which he needs for his work. The style of the writer is delightfully fresh and easy, his pictures of the ancient "marine service" being extraordinarily clear and comprehensive. Hardy's father, in "Tom Brown," might here find some of his doubts concerning the triremes, settled quite effectually. Com. Parker, first having received the statements of the past, is not always inclined to rely wholly upon them, but with critical acumen separates the probable from the improbable, his judgment so well founded by personal experience and careful study being certainly worthy of the highest respect. From a major part of the volume we can judge the whole, we think, and commend it in advance to the attention of our readers, as a most able production in a new field. In conclusion, we can only say, it is exceedingly pleasant to note the devotion of his leisure time to literary pursuits wholly beneficial to the community about him, of a gentleman whose skill in his profession is always acknowledged.—*Boston Traveler.*

KNIGHT'S AMERICAN MECHANICAL DICTIONARY: A Descriptive Word-book of Tools, Instruments, Machines, Chemical and Mechanical Processes etc., etc. By EDWARD H. KNIGHT, A. M, Civil and Mechanical Engineer. Boston: H. O. Houghton and Company. For sale by D. Van Nostrand. Price $8.00 per vol. in cloth.

The third volume of this excellent work is just issued. It will prove indispensable to all whose interest involves a knowledge of mechanical appliances, or even of a history of their origin and use, for the work is a history of inventions as well as an Encyclopedia.

The Author has invented a system of what he terms "SPECIFIC INDEXES," by the use of which the inquirer is guided straight to the information he is in quest of, even though he be entirely ignorant of the name of a thing, and have but the most vague and general notion of its use. This is accomplished by grouping under the general title of each science, art, trade, or profession, a list, or "specific index," of every article in the book bearing any relation to the subject in question. The titles of these Indexes are in turn grouped on page v., Vol. 1, so that by a glance one may determine which clew to follow.

This work is the result of twenty-five years' application, much of the time having been passed by the Author in the United States Patent Office, where he was engaged in editing the Patent Office Report, and classifying patents; and subsequently editing the "Official Gazette," and systematizing for examination the 20,000 applications for patents which yearly are presented to the office. Sitting at the very center and focus of the mechanical thought of the country, he saw the necessity for a compendious Description of the Tools, Machines, Processes, and Appliances of the Arts and Sciences,—in short, a *Dictionary of Mechanical Terms.*

The work treats of 20,000 subjects, and is illustrated with 7,500 carefully prepared engravings. It would indeed be correct to say that the illustrations are fully 15,000 in number, in as much as a variety of distinct forms of a machine or tool (sometimes as many as forty) are frequently associated in a single cut, and might, had the object been to spread them out and make a show, have been enumerated as separate figures.

After eight years of active preparation, the work has just been completed, and may be had, *by subscription only*, in forty-four parts of sixty four pages each, or in three bound volumes.

FORMULAE FOR THE CALCULATION OF EARTHWORK. By JOHN WOODBRIDGE DAVIS C. E. New York: J. Dickson & Bro. Printers.

The author presents as new the following topics, viz:. First, the inclusion of volumes of minor length in the general series, whereby the inequality in length of consecutive volumes forms no interruption to a single and speedy operation. Next, the attainment of a single formula for all varieties of irregular and defective volumes, which not only abbreviates the computation of each, but allows them all to be included in the same series with ordinary volumes, so that any entire cut or bank can be estimated accurately in one operation. Approximate formulæ, on account of their simplicity, are used in the combinations, and the results corrected by an exceedingly easy formula, thus obtaining the contents as by the prismoidal rule.

Although the original idea of the author was to secure the maximum amount of brevity, by combining everything without exception in series, and then eliminating every constant factor and term from the calculation of each, inventing for this purpose, several devices not hitherto used, yet he has not allowed himself to be tempted away from exact work, deeming this to be of the first importance.

The claim for the method is *absolute accuracy*, joined with what brevity is shown to arise from the use of the resulting formulæ.

The work is used as a text book in the School of Mines, Columbia College.

QUALITATIVE CHEMICAL ANALYSIS: A Guide in the Practical Study of Chemistry and in the Work of Analysis. By Prof. SILAS H. DOUGLAS and Prof. ALBERT B. PRESCOTT. Second Edition Revised. New York: D. Van Nostrand. Price $3.50

This enlarged edition of an excellent work has grown out of Douglas' Tables for Qualitative Analysis, first published about twelve years since. These tables soon became widely known to students, so that a second and a third edition quickly followed.

The first edition of the present work, representing the joint labors of the two writers, appeared three years ago. The present edition, just out of the press, embodies much additional matter, and is carefully made to accord with the recent confirmed discoveries in practical chemistry. It is especially designed for a text book for students, while each section has been expanded beyond the immediate requirements of the beginner, to the extent of serving the purposes of the practised analyst. Two kinds of type serve to point out the division between the section and its supplementary portion.

Some differences between this work and the ordinary works on Analysis, are observed in the treatment of the "Iron Group." The procedure is made to depend upon the presence or absence of Phosphates, so that when the process of search has reached this third group, the evidence of phosphoric acid is sought for. If absent, Ammonium Chloride and Ammonium Hydrate, are added to separate the pseudo-triads. Iron Chromium and Aluminum as a sub-group; then the remainder of the third group are precipitated in the old way.

This is not given to the exclusion of the former method, only as a valuable addition to it.

Some new reactions of the rarer metals are given, and a valuable table of solubilities of metallic salts. The new notation is used throughout.

MISCELLANEOUS.

FURNACE LINING.—M. E. P. Audouin of Paris, France, has invented a composition which he says is calculated to more effectually resist the action of oxide of iron than any other material heretofore employed for the purpose. This material is oxide of chromium, which is capable of resisting the very highest temperatures employed in furnaces and laboratories—such as the Siemens furnace, and furnaces heated by dead oils—and is also proof against the action of oxide of iron at the highest degrees of heat. The inventor claims that there is no danger of the oxide being reduced under the ordinary conditions of working; and, moreover, the presence of a small quantity of chromium will not affect the quality of the iron. This oxide may also be utilized in the manufacture of fireproof blocks to be exposed to the action of furnace cinder and scoria, but with less advantage, as by the action of certain principles, more especially potash, soda, and lime, chromates are eventually found.

THE NEW TARGET AT SHOEBURYNESS.—The iron target for testing the powers of the 38-ton gun is now ready in the marshes at Shoeburyness. It consists of three plates of rolled iron, ten feet by eight feet, each 6½ inches thick, and weighing nine tons. Between the plates are layers of teak five inches in thickness, and they are all bolted together by sixteen 3-inch bolts, eight others attaching the structure to the timber strutting in rear. The strutting consists of three piles, fourteen inches in diameter and fifteen feet long, and of three shorter piles seven feet behind, but connected by braces framed and bolted. The row of short piles butts up against an old iron target, also strutted with timber. To increase the stability of the target, its sides are strutted by means of old 6-inch plates held in position by the rods passing in front and rear, and these are also braced. The top of the target is covered with an old 8-inch plate, and is secured by railway bars bolted underneath the plate, and through the old target at the back. The trial will consist of only one round, and although 19½ inches of iron (without reckoning the wood) is more than the gun has yet attempted to penetrate, it is believed that it will accomplish the task.

USE OF SULPHATE OF ALUMINA FOR THE PRECIPITATION OF SEWAGE.—The question of the utilization of sewage has again come before the French Academy of Science, this time in connection with the discovery of a large bed of kaolin in the department of Mayenne. It is well known that sulphate of alumina has often been proposed as an agent for precipitating the organic matter contained in sewage, and that experiments on a large scale have been made. M. Cagnant, the discoverer of the bed of china-clay, is of opinion that the possibility of manufacturing this salt at a much lower price than heretofore will permit of extending the experiments, and of arriving at more satisfactory results than have hitherto been obtained. M. Belgrand, however, observed that the high price of the re-agent was not the only reason why its use as a precipitant had been rejected. The construction of basins sufficiently large for the treatment of the enormous quantity of water used daily by the capital would lead to an expense out of all proportion to the value of the products that must be obtained; the removal of the deposits formed in the basins would involve a considerable amount of labor; and this practice would be as deleterious to health as leaving the sewage in the river. M. Belgrand was convinced that, regard being had to the volume of water to be got rid of, the best method after all, was to utilize the sewage itself, as a vehicle for the fertilizing matters it may contain, and that irrigation is the only method really practicable, provided, however, that it be practised over a sufficiently large area.

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NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

II.

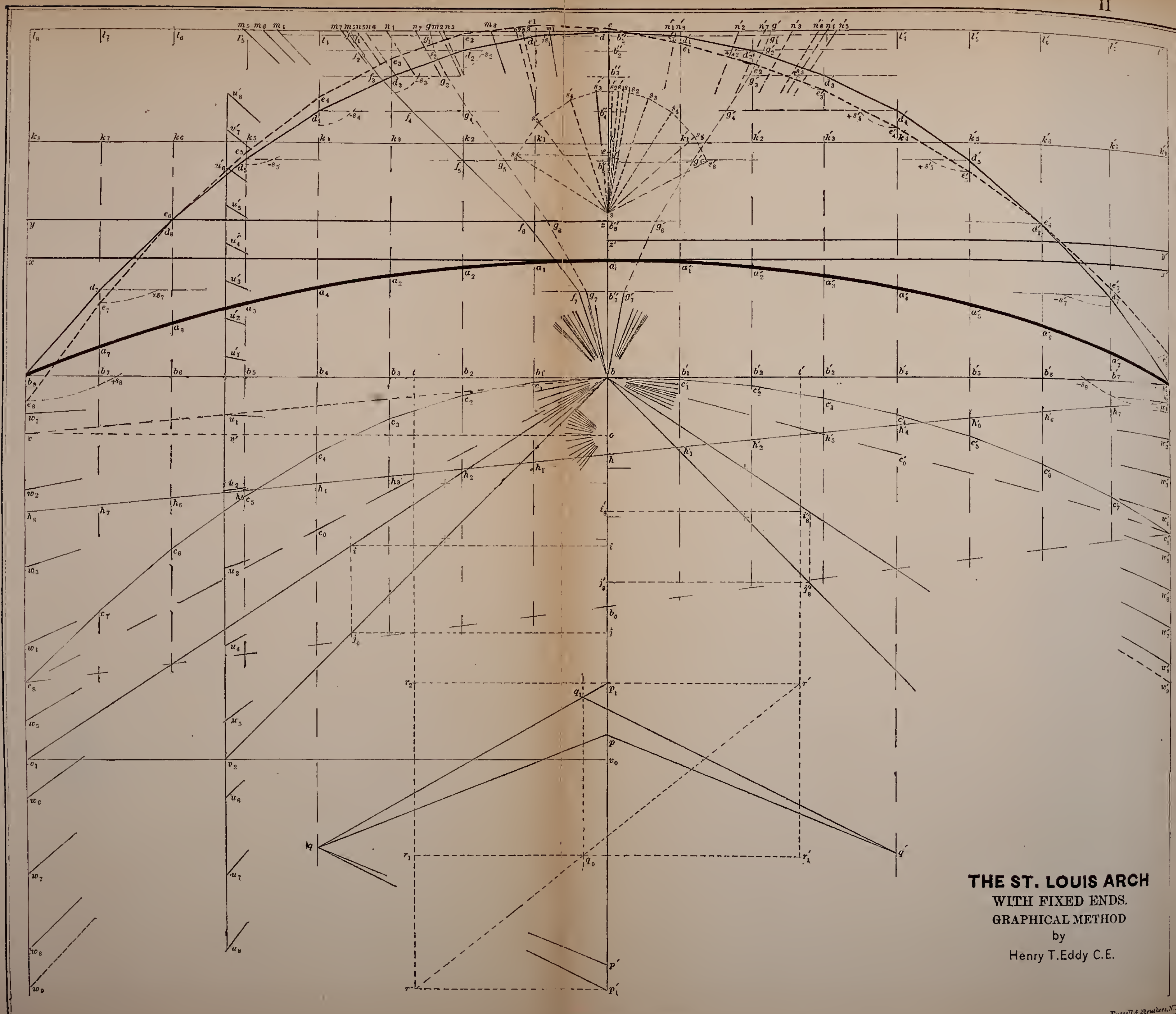
THE ARCH RIB WITH FIXED ENDS.

LET us take, as the particular case to be treated, that of the St. Louis Bridge, which is a steel arch in the form of the arc of a circle; having a chord or span of 518 feet and a versed sine or rise of one-tenth the span, *i. e.* 51.8 feet. The arch rib is firmly inserted in the immense skew-backs which form part of the upper portion of the abutments. It will be assumed that the abutments do not yield to either the thrust or weight of the arch and its load, which was also assumed in the published computations upon which the arch was actually constructed. Further, we shall for the present assume the cross section of the rib to have the same moment of inertia, I, at all points, and shall here only consider the stresses induced by an assumed load. The stresses due to changes in the length of the arch itself, due to its being shortened by the loading, and to the variations of temperature, are readily treated by a method similar to the one which will be used in this article, and will be treated in a subsequent article.

Let $b_8\,a\,b_8'$ in Fig. 2, be the neutral axis of the arch of which the rise is one-tenth the span. Let $a\,x\,y\,z$ be the area representing the load on the left half of the arch, and $a\,x'\,y'\,z'$ that on the right, so that $yp=aP=xy$ on the left, and $yp=x'y'$ on the right.

Divide the span into sixteen equal parts bb_1, bb_1', etc, and consider that the load which is really uniformly distributed is applied to the arch at the points a, a_1, a_1', etc., in the verticals through b, b_1, b_1', etc.; so that the equal weights P are applied at each of the points on the left of a and the equal weights $\frac{1}{2}P$ at each point on the right of a, while $\frac{3}{4}P$ is applied at a.

Take b as the pole of a force polygon for these weights, and lay off the weights which are applied at the left of a on the vertical through b_8, viz., $b_8\,w_1=\frac{1}{2}P=$the weight coming to a from the left; $w_1\,w_2=P=$the weight applied at a_1; $w_2\,w_3=P=$the weight applied at a_2, etc. Using b still as the pole, lay off $b_8'\,w_1'=\frac{1}{4}P=$the weight coming to a from the right; $w_1'\,w_2'=\frac{1}{2}P=$the weight applied at a_1', etc. This amounts to the same thing as if all the weights were laid off in the same vertical. Part are put at the left and part at the right for convenience of construction. Now draw bw_1 until it intersects the vertical 1 at c_1; then draw $c_1\,c_2 \parallel bw_2$; and $c_2\,c_3 \parallel bw_3$,



THE ST. LOUIS ARCH
WITH FIXED ENDS.
GRAPHICAL METHOD
by
Henry T. Eddy C.E.

Russell & Struthers, N.Y.

etc. In the same manner draw bw_1' to c_1'; then $c_1'c_2' \parallel bw_2'$, etc. Then the broken line $bc_1 \ldots c_8$ is the equilibrium polygon due to the weights on the left of a, and $bc_1' \ldots c_8'$ is that due to the weights on the right. Had the polygon been constructed for the uniformly distributed load (not considered as concentrated) on the left we should have a parabola passing through the points $bc_1 \ldots c_8$, and another parabola on the right through $bc_1' \ldots c_8'$. From the properties of this parabola it is easily seen that c_8 must bisect $w_4 w_5$, as c_8' must also bisect $w_4' w_5'$; which fact serves to test the accuracy of our construction. This test is not so simple in cases of more irregular loading.

The equilibrium polygon $c_8\, b\, c_8'$ is that due to the applied weights, but if these weights act on a straight girder with fixed ends, this manner of support requires that the total bending be zero, when the sum is taken of the bending at the various points along the entire girder; for, the position of the ends does not change under the action of the weights, hence the positive must cancel the negative bending. To express this by our eqs.:

$$yb=e.\ \Sigma(M)=0\ \therefore\ \Sigma(M)=0.$$

This is one of two conditions which are to enable us to fix the position of the true closing line $h_8 h_8'$ in this case. The other condition results from the fact that the algebraic sum of all the deflections of this straight girder must be zero if the ends are fixed horizontally.

This is evident from the fact that when one end of a girder is built in, if a tangent be drawn to its neutral axis at that end, the tangent is unmoved whatever deflections may be given to the girder; and if the other end be also fixed, its position with reference to this tangent is likewise unchanged by any deflections which may be given to the girder. To express this by our eqs.:

$$yd=f.\ \Sigma\ (Mx)=0\ \therefore\ \Sigma\ (Mx)=0$$

The method of introducing these conditions is due to Mohr. Consider the area included between the straight line $c_8 c_8'$ and the polygon $c_8\, b\, c_8'$ as some species of plus loading; we wish to find what minus loading will fulfill the above two conditions. Evidently the whole negative loading must be equal numerically to the whole positive loading, if we are to have $\Sigma(M)=0$. Next, as the closing line is to be straight, the negative load $c_8\, c_8'\, h_8\, h_8'$ may be considered in two parts, viz., the two triangles, $c_8\, c_8'\, h_8$ and $c_8'\, h_8\, h_8'$. Let the whole span be trisected at t and t', then the total negative loading may be considered to be applied in the verticals through t and t', since the centers of gravity of the triangles fall in these verticals. Again, the positive loading we shall find it convenient to distribute in this manner: viz., the triangle $c_8\, b\, c_8'$ applied in the vertical through b, the parabolic area $b\, c_1 \ldots c_8$ in the vertical 4 which contains its center of gravity, and the parabolic area $bc_1' \ldots c_8'$ in 4′.

Now these areas must be reduced to equivalent triangles or rectangles, with a common base, in order that we may compare the loads they represent. Let the common base be half the span: then $bb_0=pp'$ is the positive load due to the triangle $c_8\, b\, c_8'$; and $\frac{2}{3}\, c_4\, c_0=pp_1$ and $\frac{2}{3}\, c_4'\, c_0'=p'p_1'$ are the positive loads due to the parabolic areas.

Now assume any point q as a pole for the load line $p_1 p_1'$ and find the center of gravity of the positive loading by drawing the equilibrium polygon, whose sides are parallel to the lines of this force polygon: viz., use qp_1 and qp as the 1st and 2nd sides, and make $pq' \parallel qp'$, and $q'q_1 \parallel qp_1'$. The first and last sides intersect at q_1; therefore the center of gravity of the positive loads must lie in the vertical through q_1.

Now the negative loading must have its center of gravity in the same vertical, in order that the condition $\Sigma\,(Mx)=0$ may be satisfied, for it is the numerator of the general expression for finding the center of gravity of the loading. The question then assumes this form: what negative loads must be applied in the verticals through t and t' that their sum may be $p_1\, p_1'$, and that they may have their center of gravity in the vertical through q_1.

The shortest way to obtain these two segments of $p_1 p_1'$ is to join r and r' which are in the horizontals through p' and p_2', and draw an horizontal through q_0, which is the intersection of $r\, r'$ with the vertical through q_1; then $r\, r_1$ and $r'\, r_1'$ are the required segments of the negative load. For, let $r\,r_2 = p_1'p_1$ and take r' as the pole of the load $r\,r_2$; then, since $r_1\,q_0 \parallel r_2\,r'$ and $q_0\,r' \parallel r\,r'$ we have the equilibrium polygon $r_1\,q_0\,r'$ fulfilling the required conditions.

Now these two negative loads $r_1\,r_2 = r_1'\,r'$ and $r\,r_1$, are the required heights of the triangles $c_8\,h_8\,c_8'$ and $c_8\,c_8'\,h_8'$; therefore lay off $c_8\,h_8 = r'\,r_1'$ and $c_8'\,h_8' = rr_1$.

The closing line $h_8\,h_8'$ can then be drawn, and the moments bending the straight girder will then be proportional to $h_1\,c_1$, $h_2\,c_2$, etc., the points of inflexion being where the closing line intersects the polygon. If the construction has been correctly made, the area above the closing line is equal to that below, a test easy to apply.

Let us now turn to the consideration of the curve of the arch itself, and treat it as an equilibrium polygon. Since the rise of the arch is such a small fraction of the span, the curve itself is rather flat for our purposes, and we shall therefore multiply its ordinates ab, $a_1\,b_1$, etc., by any number convenient for our purpose: in this case, say, by 3. We thereby get a polygon $d_8\,d\,d_8'$ such that $d\,b = 3\,ab$, $d_1\,b_1 = 3\,d_1\,b_1$, etc. If a curve be described through $d_8 \ldots d \ldots d_8'$ it will be the arc of an ellipse, of which d is the extremity of the major axis.

If we wish to find the closing line $k_8 k_8'$ of this curve, such that it shall make $\Sigma\,(Md) = 0$ and $\Sigma\,(Mdx) = 0$, the same process we have just used is here applicable; but since the curve is symmetrical, the object can be effected more easily. By reason of the symmetry about the vertical through b, the center of gravity of the positive area above the horizontal through b lies in the vertical through b. The center of gravity of the negative area lies there also; hence the negative area is symmetrical about the center vertical; the closing line must then be horizontal. It only remains then to find the height of a rectangle having the same area as the elliptical segment, and having the span for its base. This is done very approximately by taking (in this case where the span is divided into 16 equal segments) $\frac{1}{8}$ the sum of the ordinates $b_1\,d_1$, etc.

We thus find the height bk and the horizontal through k is the required closing line.

Before effecting the comparison which we intend to make between the polygons c and d (as we may briefly designate the polygons $c_8\,b\,c_8'$ and $d_8\,d\,d_8'$), let us notice the significance of certain operations which are of use in the construction before us. One of these is the multiplication of the ordinates of the polygon or curve a to obtain those of d. If a was inverted, certain weights might be hung at the points a_1, a_2, etc., such that the curve would be in stable equilibrium, even though there are flexible joints at these points. Equilibrium would still exist in the present upright position under these same applied weights, though it would be unstable. If now, radiating from any point, we draw lines, one parallel to each of the sides aa_1, $a_1\,a_2$, aa_1', etc., of the polygon, then any vertical line intersecting this pencil will be cut by it in segments, which represent the relative weights needed to make a their equilibrium polygon. By drawing the vertical line at a proper distance from the pole, its total length, *i. e.*, the total load on the arch can be made of any amount we please. The horizontal line from the pole to this vertical will be the actual horizontal thrust of the arch measured on the same scale as the load. If a like pencil of radiating lines be drawn parallel to the sides of the polygon d and the load be the same as that we had supposed upon the polygon a, it is at once seen that the pole distance for d is one-third of that for a; for, every line in d has three times the rise of the corresponding one in a, and hence with the same rise, only one-third the horizontal span. The increase of ordinates, then, means a decrease of pole distance in the same ratio, and vice versa. As is well known, the product of the pole distance by the ordinate of the equilibrium polygon is the bending moment. This product is not changed by changing the pole distance.

Again, suppose the vertical load-line of a force polygon to remain in a given position, and the pole to be moved vertically to a new position. No vertical or horizontal dimension of the force polygon is affected by this change, neither will any such dimension of the equilibrium polygon corresponding to the new position of the pole be different from that in the polygon corresponding to the first position of the pole; the direction of the closing line, however, is changed. Thus we see that the closing line of any equilibrium polygon can be made to coincide with any line not vertical, and that its ordinates will be unchanged by the operation. It is unnecessary to draw the force polygon to effect this change.

Now to make clear the relationship between the polygons *c* and *d*, let us suppose, for the instant, that the polygon *e* has been drawn by some means as yet unknown, so that its ordinates from *d*, viz., $e_1\,d_1=y_1$, $e_2\,d_2=y_2$, etc., are proportional to the actual moments Me which tend to bend the arch.

The conditions which then hold respecting these moments Me, are three:—

$$\Sigma\,(Me)=0,\ \ \Sigma\,(Mex)=0,\ \ \Sigma\,(Mey)=0.$$

The first condition exists because the total bending from end to end is zero when the ends are fixed. The second and third are true, because the total deflection is zero both vertically and horizontally, since the span is unvariable as well as the position of the tangents at the ends. These results are in accordance with Prop. V. Now by Prop. III these moments Me are the differences of the moments of a straight girder and of the arch itself; hence the polygon *e* is simply the polygon *c* in a new position and with a new pole distance. As moments are unchanged by such transformations, let us denote these moments by Mc. We have before seen that

$$\Sigma\,(Mc)=0, \text{ and } \Sigma\,(Mcx)=0$$

Subtract

$$\therefore\ \Sigma\,(Mc-Me)=0, \text{ and } \Sigma(Mc-Me)x=0$$

$$\therefore\ \Sigma\,(Md)=0 \text{ and } \Sigma\,(Mdx)=0$$

From this it is seen that the polygon *d* must have its closing line fulfill the same conditions as the polygon *c*. This is in accordance with Prop. IV.

$$\text{Again, } \Sigma\,(Mey)=\Sigma\,(Mc-Md)\,y=0$$

$$\therefore\ \Sigma\,(Mcy)=\Sigma\,(Mdy).$$

This last condition we shall use for determining the pole distance of the polygon *e*, which is one-third of the actual thrust of the arch measured on the scale of the weights $w_1\,w_2$, etc. The physical significance of this condition may be stated according to Prop. V, thus: if the moments Md are applied to a uniform vertical girder *bd* at the points b, b_7'', b_6'', b_5'', etc., at the same height with d_8, d_7, etc., they will cause the same total deflection $xd=\Sigma\,(Mdy)$ as will the moments Mc when applied at the same points. Hence if Md are used as a species of loading, we can obtain the deflection by an equilibrium polygon. Suppose the load at d_7 is $d_7\,k_7$, and that at d_6 is $d_6\,k_6$, etc., then that at d_8 is $\frac{1}{2}\,b_8\,k_8$. This approximation is sufficiently accurate for our purposes.

Now lay off on $l_8\,l_8'$ as a load line $dm_8=\frac{1}{2}\,b_8\,k_8$, $m_8\,m_7=d_7\,k_7$, $m_7\,m_6=d_6\,k_6$, etc. The direction of these loads must be changed when they fall on the other side of the line k; *e.g.*, $m_5\,m_4=k_4\,d_4$. If this process be continued through the entire arch m_5' (not drawn) will fall as far to the right of *d* as m_5 does to the left, and the last load will just reach to *d* again. This is a test of the correctness with which the position of the line $k_8\,k_8'$ has been found. Now using any point as *b* for a pole, draw bm_8 to f_7, then draw $f_7\,f_6 \parallel bm_7$, $f_6 f_5 \parallel bm_6$, etc. The curve *bf* is then the exaggerated shape of a vertical girder *bd*, fixed at *b*, under the action of that part of moments Md which are in the left half of the arch. The moments Md on the right may act on another equal girder, having the same initial position *bd*, and it will then be equally deflected to the right of *bd*. This is not drawn.

Again, suppose these vertical girders fixed at *b* are bent instead by the moments Mc. We do not know just how much these moments are, though we do know that they are proportional to the ordinates of the polygon *c*. Therefore make $dn_8=\frac{1}{2}\,h_8\,c_8$, $n_8\,n_7=h_7\,c_7$, $n_7\,n_6=h_6\,c_6$, etc. When all these loads are laid off, the last one $n_8'\,d=\frac{1}{2}\,h_8'\,c_8'$ must just return to *d*. This tests the accuracy of the work in determining the position of $h_8\,h_8'$.

Now using *b* as a pole as before, construct the deflection curves *bg* and *bg'*. Since these two deflections, viz., 2 *df* and *gg'* ought to be the same, this fact informs us that each of the ordinates $h_1\,c_1$, $h_2\,c_2$, must be increased in the ratio of $\frac{1}{2}\,gg'$ to *df*, in order that when they are considered as loads, they may produce a total deflection equal to 2 *df*. To effect this, lay off $bj=df$ and $bi=\frac{1}{2}\,gg'$, and draw the horizontals through *i* and *j*. At any convenient distance draw the vertical $i_0 j_0$, and draw bi_0 and bj_0. These last two lines enable us to effect the required proportions for any ordinates on the left, and these or two lines of the same slope on the right to do the same thing on the right. *E. g.* lay off the ordinate $bi_8' = h_8' c_8'$, then the required new ordinate is bj_8'. Then lay off $k_8' e_8' = bj_8'$. In the same manner find ke from hb, and $k_8 e_8$ from $h_8 c_8$. In the same manner can the other ordinates $k_1 e_1$, etc., be found; but this is not the best way to determine the rest of them, for we can now find the pole and pole distance of the polygon *e*.

As we have previously seen, the pole distance is decreased in the same ratio as the ordinates of the moment curve are increased, therefore prolong bi_0 to v_1, and draw a horizontal line through v_1 intersecting bj_0 at v_2 and the middle vertical at v_0; then is $v_2 v_0$ the pole distance decreased in the required ratio. Hence we move up the weight-line $w_1 w_8$ to the position $u_1 u_8$ vertically through v_2; and for convenience, lay off the weights $w_1' w_2'$ at $u_1' u_2'$, etc.

Furthermore, we know that the new closing-line is horizontal. To find the position of the pole *o* so that this shall occur, draw *bv* parallel to hh_8, and from *v* the horizontal *vo*. As is well known, *v* divides the total weight into the two segments, which are the vertical resistances of the abutments, and if the pole *o* is on the same horizontal with *v*, the closing line will be horizontal.

Now having determined the positions of the points e_8, e, e_8', starting from one of them, say e_8, draw $e_8 e_7 \parallel ou_8$, $e_7 e_6 \parallel ou_7$, etc.; then if the work be accurate, the polygon will pass through the other two points *e* and e_8'. The bending moments of the arch *d* or the arch *a* at a_1, a_2, etc., is the product of the pole distance $v_0 v_2 = v'o$ by the ordinates $d_1 e_1$, $d_2 e_2$, etc., respectively, and between these points a similar product gives the moment with sufficient accuracy. It would be useful for the sake of accuracy to multiply the ordinates of the arch by some number greater than 3.

As a final test of the accuracy of the work, let us see whether $\Sigma(Mey)$ is actually zero, as should be. At d_7, for example, $y = d_7 l_7$ and *Me* is proportional to $d_7 e_7$. Then $\overline{d_7 s_7}^2$ is proportional to *Mey* at that point if $e_7 s_7$ is the arc of a circle, of which $e_7 l_7$ is the diameter. Similarly find $d_7' s_7'$, etc. When e_4 for example falls above d_4, the circle must be described on the sum of $l_4 d_4$ and $d_4 e_4$ as a diameter, and $\overline{d_4 s_4}^2$ is proportional to a moment of different sign from that at d_7. We have distinguished the sign of the moments at the different points along the arch, by putting different signs before the letter *s*. It would have been slightly more accurate to have used only one-half the ordinates $b_8 e_8$ and $b_8' e_8'$, but as they nearly equal in this case and of opposite sign, we have introduced no appreciable error.

Now at any point *s* lay off $ss_7 = d_7 s_7$, and at right angles to it $s_7 s_8 = b_8 s_8$, then at right angles to the hypothenuse ss_8 make $s_8 s_5' = d_5' s_5'$, etc. Then the sum of the positive squares is ss_1', and similarly the sum of the negative squares is ss_1. If these are equal, then $\Sigma(Mey)$ vanishes as it should, and the construction is correctly made.

It would have been equally correct to suppose the two vertical girders fixed at *d*, and bent by the moments acting. We could have determined the required ratio equally well from this construction. Further, in proving the correctness of the construction by taking the algebraic sum of the squares, we could have reckoned the ordinates, *y*, from any other horizontal line as well as from $l_8 l_8'$.

To find the resultant stress in the different portions of the arch, we must prolong $v'o$ to o', say, (not drawn) so that the pole distance $v'o' = 3\,v'o$; then if we join o' and u_8, $o'u_8$ will be the resultant stress in the segment $b_8 a_7$; $o'u_7$ will be the stress in $a_7 a_6$, etc., measured in the same scale as the weights $w_1 w_2$, etc.

The vertical shearing stress is constructed in the same manner as for a girder, by drawing one horizontal through w_8 between the verticals 7 and 8, another through w_7 between 7 and 6, etc. (not drawn). Then the shear will be the vertical distance between *vo* and these horizontals through w_8, w_7, etc. It is seen that the shear will change sign on the vertical through b_1 with our present loading.

The actual position of the vertical through the center of gravity of the load may be found by prolonging the first and last sides of the polygon *c*. A weight $= \frac{1}{2} P = w_8 w_9$ ought, however, first to be applied at b_2, and another $= \frac{1}{4} P = w_8' w_9'$ at b_8'. The shearing stress under a distributed load will actually change sign on this vertical. It will not pass far however from b_1.

The vertical shearing stress and resultant stress can be compounded and then resolved into normal and tangental components, if we should desire to obtain the stress along the arch and the normal shear.

As to the position of the moving load which will produce the maximum bending moments, we may say that the position chosen, in which the moving load covers one-half the span, gives in general nearly this case. It is possible, however, to increase one or two of the moments slightly by covering a little more than half the span with the moving load.

The maximum resultant stress and maximum vertical shear occur in general when the moving load covers the whole span. The construction in this case is much simplified, as the polygon *c* is then the same on the right of *b* as it now is on the left, and the center of gravity of the area is in the center vertical; so that the closing line $h_8 h_8'$ is horizontal, and can be drawn with the same ease as $k_8 k_8'$ was drawn. We shall not, even in this case, be under the necessity of drawing the curves *bg* and *bg'*, which would be both alike; for, as may be readily seen, the sum of the positive moments *Mc* on the left must be very approximately equal to the positive moments *Md* on the left, and the same thing is true for the negative moments at the left. The same two equalities hold also on the right. From this we at once obtain the ratio by which the ordinates of the polygon *c* must be altered to obtain those of the polygon *e*.

This last approximation also shows us that for a total uniform load, the four points of inflection when the bending moment is zero, lie two above and two below the closing line. It is frequently a sufficiently close approximation in the case when the moving load covers only part of the span to derive the ratio needed by supposing that the sum of all the ordinates, both right and left, above the closing line in the polygon *c* must be increased, so that it shall equal the corresponding sum in the polygon *d*. If the sums taken below the closing lines give a slightly different result, take the mean value.

Thus the single construction we have given in Fig. 2, and one other much simpler than this, which can be obtained by adding a few lines to Fig. 2, give a pretty complete determination of the maximum stresses on the assumptions made at the commencement of the article.

One of these assumptions, viz., that of constant cross section (*i. e.* I=constant), deserves a single remark. In the St. Louis arch I was increased one-half at each end for a distance of one-twelfth of the span. This very considerable change in the value of I slightly reduced the maximum moments computed for a constant cross section. From other elaborate calculations, particularly those of Heppel,* on the Britannia Tubular Bridge, it appears that the variation in the moments caused by the changes in cross section, which will adapt the rib to the stresses it must sustain, are relatively small, and in ordinary cases are less than five per cent. of the total stress. The same considerations are not applicable near the free ends of a continuous girder, where I may theoretically vanish. In the case before us, where the principal part of the stress arises not from the bending moments, but from the compression along the arch, the effect of the variation of I is very inconsiderable indeed.

* *Philosophical Magazine*, Vol. 40, 1870.

Menessier's Oscillating Puddling Furnace.—In the *Bulletin du Comité des Forges de France*, No. 112, for April 20th, 1876, will be found a communication made by M. Menessier to the Société de l'Industrie Minerale de St. Etienne, in which he describes a mechanical puddling furnace of his invention, which has been in work during the last seven or eight months at the Forges d'Ouzion, near St. Chamond. Full details of the working of this furnace are given, but space does not permit of our more than referring to the paper itself for particulars.

ON A GENERAL METHOD OF PRODUCING EXACT RECTILINEAR MOTION BY LINKWORK.

By A. B. KEMPE, B. A.

Proceedings of the Royal Society.

SINCE the invention by James Watt, in 1784, of the three bar linkwork known as "Watt's Parallel Motion," which gives an approximate rectilinear motion, many attempts have been made to obtain a more perfect solution of the problem how to obtain accurate rectilinear motion by means of linkwork. Prof. Tchebicheff succeeded in obtaining a three bar linkwork giving a much closer approximation to a true result; but in his case, as in that of others, the solution is only approximate, and it may be, in fact, shown that with three bars an accurate result cannot be obtained. It was not until 1864 that the problem was solved; in that year M. Peaucellier made his memorable discovery of an accurate seven bar solution; and in 1874, when the subject was brought prominently forward in England by Prof. Sylvester, Mr. Hart, in a paper read before the British Association, gave a solution by means of five bars. Both these linkworks, as is now well known, depended upon the inversion of a circle with respect to a point on its circumference.

M. Peaucellier's apparatus is shown in Fig. 10. P O, O K, K D, D P and four equal bars jointed together at their extremities ; P B, K B are two bars also equal, but unequal to the four others; they are jointed to the others at P and K and to a fixed pivot at B. It is then easily seen that, however this linkage* is deformed, B, O, D remain in a straight line, and the product B O, B D is constant. Thus if D be made, by means of the bar A D jointed to the fixed point A, whose distance from B equals A D, to describe a circle through B, the point O will describe the inverse of the circle—that is, the straight line O L perpendicular to B A.

Mr. Hart's apparatus is shown in Fig. 15. For the six bars B P, B K, O P, P D, D K, K O of M. Peaucellier in Fig. 10 he substitutes the four bars

$$B C = B' C', \quad C D = C' D',$$

and takes three points, P, O, V, on a line parallel to C C′; these points, however the linkage be deformed, lie in a straight line, and the product P V, P O is always constant.

Thus V being made, by the bar V U equal to P U and pivoted at U, to describe a cirle passing through the fixed point P, as in the case of M. Peaucellier's linkwork, O describes the straight line O L perpendicular to P U.

A passage in a lecture on M. Peaucellier's discovery delivered by Professor Sylvester at the Royal Institution, in which he pointed out that there might be other solutions, led me to investigate the subject further; and I succeeded in obtaining certain seven bar linkworks producing rectilinear motion, depending on two bars being made to make equal variable angles in opposite directions with a third bar. These results were described in a paper published in the *Messenger of Mathematics* of December, 1874; they are shown in Figs. 6, 12, 13, 14 of this paper, and will be further referred to.

Further investigation led me to the discovery that all these linkworks depended for their production of straight lines on an exceedingly simple and obvious property of any quadrilateral whose sides are of constant length. The observation of this property at once led to the discovery of a large number of new seven bar linkworks, of which M. Peaucellier's, Mr. Hart's, and those previously discovered by myself proved to be particular cases, the inversion property of the two former being, so to say, accidental.

It is the object of this paper to point out this property, and how it may be taken advantage of in the construction of a number of seven bar straight-line-producing linkworks.

The property alluded to is this:

The cosines of the opposite angles of any quadrilateral whose sides are of constant length, but whose angles are variable, bear a linear relation to each other.

§ 1. In Fig. 1, A B C D is any quad-

* Professor Sylvester has employed this term to mean a network composed of an even number of bars. When one bar is fixed, so that its joints become fixed pivots, the system is termed a linkwork.

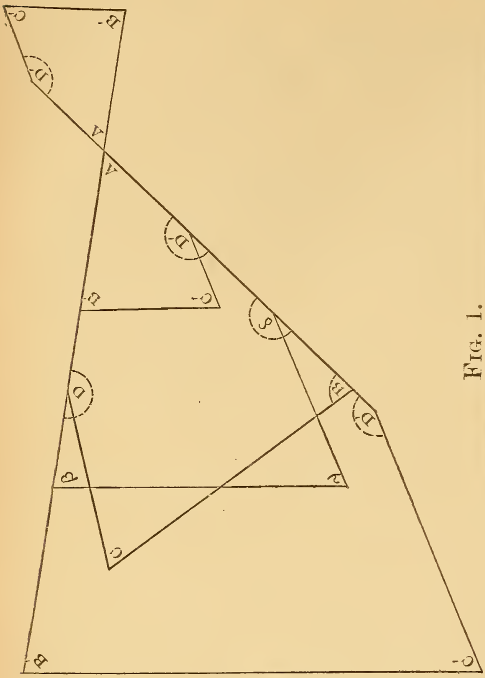


Fig. 1.

rilateral of which the sides A B, B C, C D, D A are of the lengths a, b, c, d respectively.

Then it is clear that

$$a^2+b^2-2ab \cos B=c^2+d^2-2cd \cos D \quad (1)$$

That is, there is a linear relation of the most general character between the cosines of the variable angles B and D.

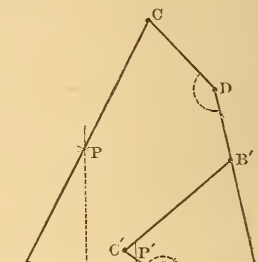
Before, however, this property can be taken advantage of something more is required; the angles whose cosines bear a linear relation to each other are the opposite angles of a closed quadrilateral; and for our purpose it is necessary that they should be the angles at the base of an open trilateral—*i e.*, to employ the language of linkwork, the angles made with a third bar by two bars which are jointed to it. To effect this transformation let the second quadrilateral A $\beta\gamma\delta$ be constructed equal in every respect to A B C D, and having its sides δ A, β A collinear with the sides B A, D A of A B C D, but placed in a reverse position so as to be the image of A B C D. This new quadrilateral may be termed the "conjugate image" of A B C D, the whole figure forming what may be termed a "self-conjugate sextilateral."

It is clear that the angle δ is equal to the angle D; thus we have the sides B C, $\delta\gamma$ of the open trilateral C B $\delta\gamma$ making angles with A B whose cosines bear a linear relation to each other however the figure be deformed.

Since, however, the relation is an angle relation, it is unnecessary that the conjugate image should be equal to the original quadrilateral; for if the Fig. A B′ C′ D′ be constructed similar to A $\beta\gamma\delta$ the angle D′ is clearly equal to the angle δ, and we have the sides C B, C′ D′ making angles with A B whose cosines bear a linear relation to each other. This makes our results more general; and we are moreover able to make the points D and B′, or the points D′ and B, coincide if necessary. This more general form of figure, consisting of two quadrilaterals, one of which is the enlarged or reduced positive or negative image of the other, may still be appropriately termed a "self-conjugate sextilateral," the quadrilaterals being still called the one the "self-conjugate image" of the other.

§ 2. Now let the linkage in Fig. 2 be constructed,

Fig. 2.



in which

in which	A B $=a$,	A B′ $=k\,a$,
	B C $=b$,	B′ C′ $=k\,b$,
	C D $=c$,	C′ D′ $=k\,c$,
	D A $=d$,	D′ A $=k\,d$,

k being positive or negative, and greater, equal to, or less than unity, so that the linkage forms a self-conjugate sextilateral, the quadrilaterals A B C D, A B′ C′ D′ being self-conjugate images the one of the other.

Now take any point P on B C, and let B P $=\lambda$, and take a point P′ on D′ C′ such that D′P′ $=\lambda\frac{cd}{ab}$. Draw P N and P′ N′ perpendicular to A B.

Then

$$B N=\lambda \cos B,$$

$$D'N' = \lambda \frac{cd}{ab} \cos D' = \lambda \frac{cd}{ab} \cos D,$$

and

$$B D' = a - kd.$$

Thus $N N' = B D' - B N + D' N'$*

$$= (a - kd) - \frac{\lambda}{2ab}[2\, ab \cos B - 2\, cd \cos D]$$

by (1)

$$= (a - kd) - \frac{\lambda}{2ab}[(a^2 + b^2) - (c^2 + d^2)] \quad . \quad (2)$$

a constant. On the other hand, $P N - P'N'$ is in general variable.

The linkage in Fig. 2, which will assume innumerable forms by giving different values to a, b, c, d, and k, is the fundamental linkage upon which the various linkworks here discussed depend. As the same lettering will be preserved throughout the diagrams, the fundamental linkage may be at once recognized in each figure showing its various adaptations.

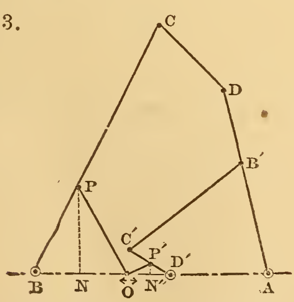
For clearness the bars are denoted by thick lines, the joints by round spots; when a bar becomes fixed so that its joints are fixed pivots, the bar is denoted by a broken line and the pivots by circles round the spots. When points in general separate are made coincident, the letters denoting all the coincident points are bracketed together. It is found convenient to collect the different linkworks into four groups, a separate section, numbered to correspond with the figure, being devoted to each separate linkwork described.

I. § 3. Take

$$\lambda = \frac{(a - kd)\, ab}{(a^2 + b^2) - (c^2 + d^2}$$

so that $N N' = \frac{B D'}{2}$.

FIG. 3.



* In the figure $D' N'$ is negative.

Then if the bar A B be fixed and two bars P O, P'O be added

$$P O = P B, \quad P'O = P'D';$$

O clearly lies on A B, however the linkwork be deformed, and its locus is therefore the straight line A B.

§ 4. If in this last linkwork we make

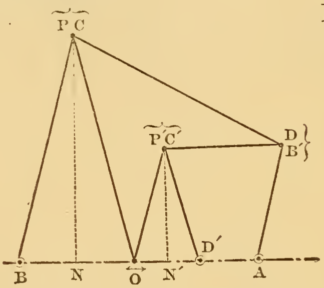
$$b = c, \; k = \frac{d}{a}, \text{ then } \lambda = b,$$

and

P coincides with C,
P′ " " C′,
B′ " " D.

The linkwork then assumes the form given in Fig. 4.

FIG. 4.



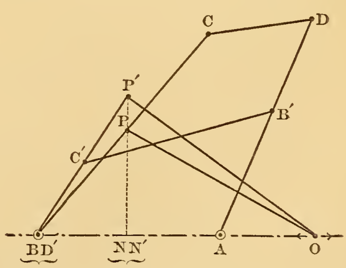
§ 5. Again, in the linkwork of § 3, if

$$k = \frac{a}{d} \text{ and } a^2 + b^2 = c^2 + d^2,$$

then $\lambda = \frac{0}{0}$ and is indeterminate. P may then be taken anywhere on B C; and since $N N' = 0$, P′ lies vertically above P. Also P O and P′ O may be taken of any lengths so long as

$$P' O^2 - P O^2 = P' B^2 - P B^2.$$

FIG. 5.



§ 6. Here we have a special case of the linkwork in the last section in which $a = -c$, $b = d$. In this case C B and C′D′ are equally inclined to B A in opposite directions; and the linkwork is one of those given by me in the *Messenger*.

§ 7. This case does not strictly come under the same head as those coming before, but is an exceptional one.

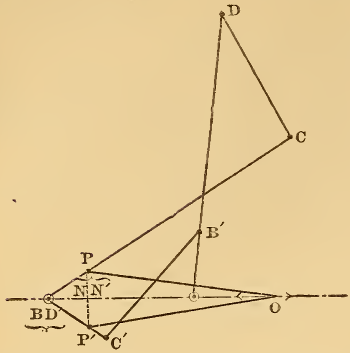


FIG. 6.

Since P and P′ in § 5 lie vertically the one over the other, it is clear that if the links P O=P′B, P′ O=P B be added, O lies on the straight line O B perpendicular to A B, and thus O B is the locus of O.

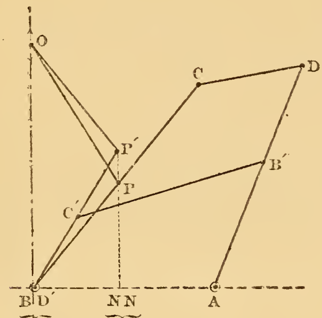


FIG. 7.

II. § 8. Make $k=\frac{a}{d}$ in the fundamental linkage, so that B and D′ coincide.

Fix A B, add the bars R P O, R P′ O′, making

$$R P = P O = P'D',$$
$$R P' = P'O' = P B,$$

then R P O is parallel to P′D′,
R P′O′ " P B.

Thus, if O L, O′L′ be drawn perpendicular to A B,

$$N L = N'D',$$
$$N'L' = B N.$$

Therefore B L=B′L′=N′N, a constant.

Thus the loci of O and O′ are two parallel straight lines perpendicular to A B.

The two added bars may clearly be replaced by the bars $\rho C \varpi$, $\rho C' \varpi'$ parallel to them; and the points ϖ, ϖ', where these bars cut the line O′ B O, will move in straight lines $\varpi\lambda$, $\varpi'\lambda$ perpendicular to A B.

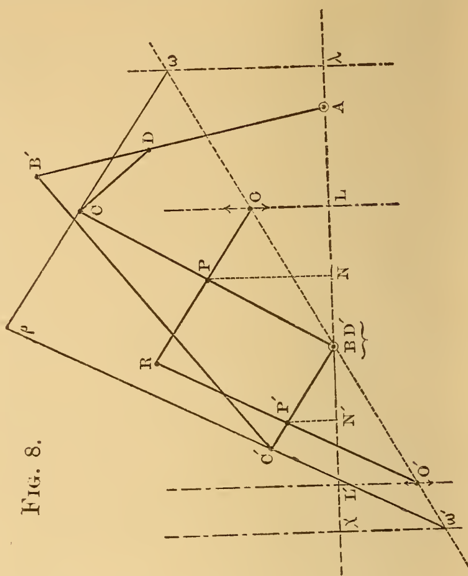


FIG. 8.

III. § 9. Fix A B.

Make $k=\frac{d}{a}$, $\lambda=b$.

Then P coincides with C,
P′ " " C′,
D " " B′,

Replace C′ D′, C′ B′ by the new bars

$$B'K = C'D', \quad D'K = C'B',$$

so that B′ K is parallel to C′ D.

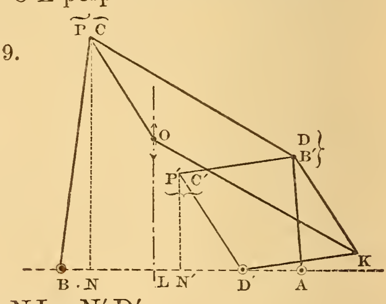
Add the two bars

$$C O = B'K, \quad K O = B'C,$$

so that P O is parallel and equal to D K, and therefore to C′ D′.

Draw O L perpendicular to A B.

FIG. 9.



Then N L=N′ D′.

Therefore B L=B N+N L=N N′, a constant.

Thus the locus of O is the straight line O L perpendicular to A B.

§ 10. Now in the last linkwork make $a=d$.

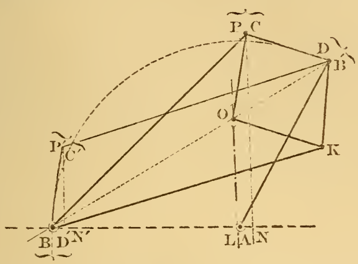
Then B coincides with D′,

D′K=C B,

P O=O K=K D=D C,

and the linkwork becomes that of M. Peaucellier.

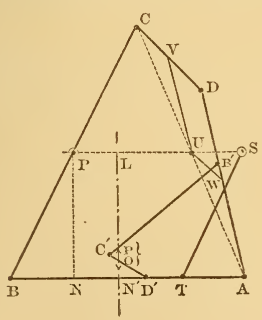
FIG. 10



IV. § 11. Taking the fundamental linkage in its most general form, fix the point P on a pivot. Now if the bar A B be made to remain always parallel to the fixed line P S, since N N′ is constant, P′ will move on the straight line P′ L perpendicular to P S.

The parallelism of A B is effected most obviously by adding the bar S T equal to P B, P S being equal to B T. Other methods may, however, be employed; for if C A be joined cutting P S in U, U is a fixed point; and if U V be drawn parallel to C D, U V is constant and V is a fixed point on C D. So if U W be drawn parallel to C D, U W is constant and W is a fixed point on A D. Thus the bar S T may be replaced by either of the bars U V or U W.

FIG. 11.



§ 12. In the case in which the bar S T is employed in the last section, make

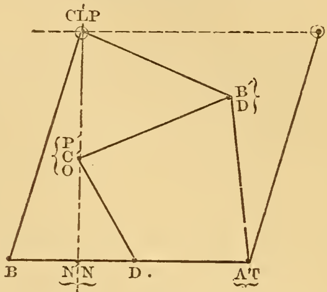
$$a=b,\ c=d,\ k=\frac{d}{a},\ \lambda=b,$$

and make T coincide with A. Then

C, L, P coincide,
P′, C′, O "
A, T "
B′, D "
N, N′ "

and the bars C D, D O are equally inclined to C S in opposite directions.

FIG. 12.



This linkwork is one of those given by me in the *Messenger*.

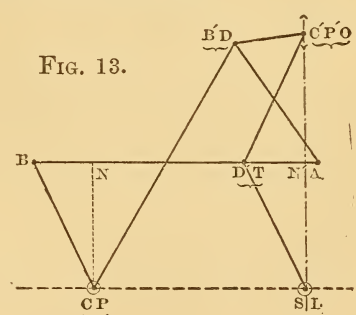
§ 13. In the linkwork of § 11 make

$a=c,\ b=-d,\ \lambda=b,\ =k\frac{d}{a},$ and make D′ and T coincide. Then

S, L coincide,
C, P "
D′, T "
C′, P′O "
B′, D "

and the bars B C, D′ C′ make equal angles with A B in opposite directions; and the linkwork is one of those given by me in the *Messenger*.

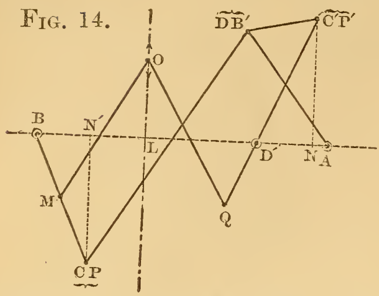
FIG. 13.



§ 14. The peculiar form of the fundamental linkwork employed in the last case may easily be seen to be really the same as was used in § 5. From the property of the equal inclination of the bars B C, D′ C′ to B A, another form of linkwork may be obtained which does not, strictly speaking, come under this group, but is an exceptional one.

C′ D′ is produced to any point Q and a point M is taken on B C such that B M=D′ Q. A B is fixed. The equal bars M O, Q O are added. Then O clearly moves on the straight O L per-

FIG. 14.

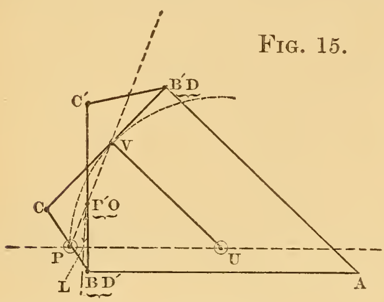


pendicular to A B, B L being equal to L D′. This linkwork was given by me in the *Messenger*.

§ 15. In the linkwork of § 11 replace the bar S T by the bar U V. Make

$$a=d,\ k=\frac{d}{a}=1.$$

FIG. 15.



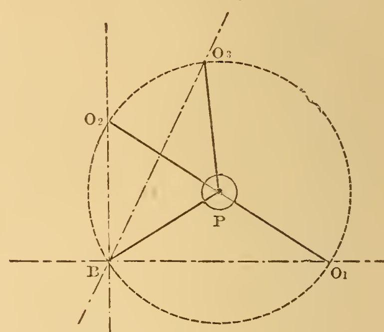
Then it will be seen that

B coincides with D′,
B′ " " D,

and the bars A D, A B become superfluous and may be removed. There then remains Mr. Hart's five bar linkwork. This is the only five bar linkwork, giving rectilinear motion that has as yet been obtained.

§ 16. In many of the previous cases the point O, which moves in a straight line, will be found to be connected to a fixed point through which the straight line passes by two equal bars. Whenever this occurs the motion of the bar containing the moving point is of the sort described by Professor Sylvester as "tram motion." That is, its motion is that of a bar sliding between two fixed rectilinear trammels, or, to present this motion in its fullest generality, the motion of a plane in which a whole series of points lying on a circle move each of them in straight lines passing through a fixed point. Turning to Fig. 16, if B P, P O_1 be equal bars and O_1 moves in the straight line O_1 B passing through B, then if O_1 P be produced to O_2 so that P O_2=P O_1, O_2 obviously moves in the straight line B O_2 perpendicular to O_1 B, so that O_1 O_2 slides between the two straight lines B O_1, B O_2. In this case it is clear that any point O_3 attached to the bar O_1 P O_2, and distant a distance P O_3=P O_1 from P, describes a straight line O_3 B through B, the angle O_3 B O_1 being one half of the angle O_3 P O_1. This greatly adds to the usefulness of the linkworks.

FIG. 16.



It is not suggested that the linkworks here given exhaust seven bar line linkworks; indeed it is obvious that many of them are susceptible of variations. Enough, however, has been shown to demonstrate the important part which the property of a quadrilateral combined with the principle of the conjugate image stated at the outset plays in the question.

I have strictly confined myself in this paper to the consideration of the rectilinear motion of a point. The principles involved, however, are applicable to many other problems, as, for example, the motion of bars every point in which moves in one of a series of parallel straight lines or in the same straight line. By means of the peculiar form of the fundamental linkage given in Figs. 6, 13, 14, valuable results in the reversal or multiplication of angular motion may be obtained, and a linkage of $2n+2$ bars may be constructed which will divide any angle into n equal parts. Some of these questions have been treated of by me in my paper in the *Messenger of Mathematics*, already referred to, which was, however, written before I obtained the general results here given. The extension of these results to other problems is reserved for future investigation.

CONTINUOUS RAILWAY BRAKES.

From "Engineering."

The importance of the railway brake problem is at last becoming rapidly recognised, not only by railway managers, but in a general way by the traveling public also. During the last few years a great acceleration of speed has come in daily practice; speeds that a short time since were highly exceptional have become the rule, and those which were once considered apocryphal are now common. But such speeds as sixty miles and upwards an hour, can only be maintained with a permanent way and rolling stock as perfect as modern appliances can make them, combined with the most rigid inspection, and maintenance of both to the highest possible standard. And with the utmost skill in construction, and with the utmost care in working, accidents must from time to time occur, and accidents occurring at such high speeds are almost necessarily attended with disastrous consequences. More than ever, then, is the complete control of trains a question of increasing necessity, and the best available means of bringing a train from a high speed to a state of rest have to be found and adopted.

On almost all of the leading railways in this country steps more or less important towards this end have been taken. On several continuous brakes are wholly or partially in use, either for the purpose of regular working, or held in reserve for cases of emergency; but for the most part railway managers are feeling their way by experiment before they commit themselves to the introduction of a costly appliance, to which they must for some time at least adhere, after they have once decided on its adoption. That the utmost caution in arriving at a decision upon this important subject is not only wise but necessary in the interests of railway shareholders is evident, but we fear that in some instances, as on the Great Western for example, there is an indifference on the subject, and possibly to prejudice, perhaps to a dislike in bringing within the British railway circle what may have come into existence outside its limits, may be traced a part of the hesitation manifested.

We have so often in these columns considered the question of continuous railway brakes, and pointed out the requirements of an efficient appliance for the control of trains, that we fear almost to become tedious by repetition. But the subject is one of so great importance that it must be our excuse for reiteration. The main requirements to be sought for in selecting a railway brake which may be placed with confidence upon high-speed trains may be summarised as follows:

1. It must be capable of application to every wheel throughout the train, if so desired.

2. It must be so prompt in its action that no appreciable loss of time occurs between the time of its application, and the moment when its full power can be exerted throughout the train.

3. It must be capable of being applied by the driver of the engine, and at any desired point throughout the train.

4. It must be capable of application by driver and guard acting in concert, or by either independently of the other.

5. It must under all circumstances be capable of arresting the motion of a train in the shortest possible distance.

6. It must be so arranged that in the event of the failure of any one of its vital parts, such failure must record itself by the application of the brakes or otherwise; so that the train, if in motion, may be automatically arrested, and the existence of a defect be thereby made known.

7. It must, in the event of a train breaking into two or more parts, be capable of immediate automatic application to every vehicle, under all conditions.

8. It must be simple in its construction and in its mode of working, and not be more liable to derangement in any of its parts than any other portion of the mechanism on the train.

9. The duties it is called upon to perform must be done by the apparatus itself, and not by the addition of any auxiliary contrivance called in to aid an appliance which cannot of itself fulfill the necessary conditions.

10. It should preferably be inexpensive for first establishment, and necessarily cheap in maintenance, for if the latter condition be not fulfilled, constant watching and frequent renewals would be required, and the eighth requirement named above would not be complied with.

This list of requirements could be extended, but it embraces almost all the most important points, which are so evident as scarcely to call for any comment. The second condition abovenamed, ranks high in importance. It makes all the difference between the safety and destruction of a high-speed train, whether two seconds or eighteen elapse between the application of the brake, and the full development of the retarding force on the wheels. A striking illustration of this occurred about two weeks since on the North British Railway, with the fast Scotch express running from Carlisle to Edinburgh. On approaching Kershopefoot about 6 A. M., the driver of the train noticed fire flash from the rails four times at very short intervals. With most praiseworthy caution, he reduced his speed to about thirty miles an hour, and almost immediately after passed over a fog signal. Upon this he applied the brakes and brought the train to a stand within ten yards of a goods train that had broken down and blocked both lines. Only about twelve seconds elapsed from the time of passing over the last fog signal which alone had exploded, until the train was brought to a stand, and the distance run in this time was probably less than 300 feet. In this case, instantaneous action of the brakes alone saved the train. This incident gives also an illustration of the importance of the driver being able to control the brakes. Had he in this instance been obliged to signal the guard, a few invaluable seconds would have been wasted, and the collision must have occurred.

A railway accident which very recently took place on the Jersey Central Railroad fully illustrates the importance of the sixth requirement. On the 11th of November last, a passenger train running to the Communipaw Ferry, instead of pulling up at the platform, dashed on with undiminished speed through the depot, carrying away a portion of the goods office, and crossing the ferry pier outside, fell into the river, carrying its cars after it. The cause was as follows: the driver, who had been in the habit of relying upon the vacuum brake with which the train was fitted, attempted as usual to stop his train, but found that the apparatus had failed, and left him helpless at the critical moment. No warning had been given of this failure, no warning, in fact, could be given; the brake was simply powerless to act when called upon, and the results above narrated occurred. But if the brake had been able to speak for itself, and to call attention to its failure by automatically stopping the train, no such accident could have occurred.

To give a third and final illustration, this time for requirement No. 7. We described recently the Heely accident to the up-Scotch express, which, when running at a very high speed, parted near Sheffield, the forward portion running on, and the rear part being broken up and leaving the rails. The separation of the train threw every brake-block into action, pulling up the undamaged portion, and so reducing the velocity of the scattered carriages that—although the brake rigging was shattered by contact with the sleepers and ballast—the brakes had done sufficient work to bring the carriages to rest with but little damage, and without serious injuries to any passenger.

We have said that a continuous brake should be complete within itself, and not be dependent for the fulfilment of its duties upon any auxiliary appliances called in to help it, and we think this will be at once seen to be an important condition. For, if it be conceded that the driver—who must be the first to see an approaching danger—should have the means of at once bringing the whole brake power available to bear, it is obvious that any appliance is imperfect and incomplete, if he has to signal for co-operation from the guards. Auxiliary appliances, too, mean complication; they mean multiplicity of parts, increased chances of derangement, increased danger of failure at a critical moment, and they mean increased first cost and maintenance charges, though these latter are of comparatively small importance. The advantages of simplicity of arrangement and non-liability to accident are so obvious as to need no remark. Given different systems equally efficient in their action, and that one will be the better which requires fifty feet instead of 100 ft. of pipe, and one instead of two couplings, which is made of the least perishable material, or which is less likely to be destroyed. Thus, on the Pennsylvania Railroad—the whole of the rolling stock of which is fitted with the Westinghouse brake—almost innumerable robberies of the couplings occurred, attended with great destruction of the rubber hose, until the material was changed from gun-metal to cast iron.

It may be considered that all the requirements we have enumerated as being essential for an efficient railway brake, cannot be combined in one apparatus. We do not propose on the present occasion to discuss whether or not such a combination has been hitherto perfected, but simply record the fact that the whole of these functions are necessary for the control of trains, and that railway managers do well in hesitating to adopt any system which is unable to perform them. We shall, however, take an early opportunity of considering how far the various brakes which have of late years been brought forward, can fill the conditions named. Two of these systems which have perhaps been more prominently before the public than any other, are of American origin; the first is the Westinghouse automatic air brake, and the other is known as Smith's vacuum brake. The arrangement and mode of working of both these systems is sufficiently familiar to our readers to prevent us from publishing it here, and both systems figured in the brake trials at Newark in the summer of last year. Since that time, however, Mr. Westinghouse, and probably Mr. Smith also, has made considerable improvements in the details of the apparatus, and in its latest form, the automatic brake, after considerable experience with it in America, is now fitted on the more important trains upon the Midland Railway, where it has been, lately, as we have seen, the means of mitigating the effect of one very serious accident, and of preventing a second upon the very verge. The good judgment and foresight of Mr. Johnson in equipping the chief and fastest trains upon his line with this appliance, have thus received abundant practical testimony. Following this example, and acting with the same earnest desire of proving by the test of actual work, which is the best continuous brake at present available, Mr. D. Drummond, locomotive superintendent of the North British Railway, has recently had two exactly similar trains equipped, the one with the Westinghouse automatic, and the other with the vacuum brake, and he proposes, first by a series of experiment, and subsequently by the results of daily work, to test these two systems, and to satisfy himself which of them nearest fulfils the necessary conditions of apparatus for the efficient control of trains.

Carried out by so able a man as Mr. Drummond—who being entirely unprejudiced, desires to ascertain what is most adapted for his line, and to use that system which experience shows him is the best—these trials will have a value, which —though far more extended—those at Newark did not possess, and we feel assured that every one, including Mr. Westinghouse and Mr. Smith, will rest satisfied with the ultimate verdict of Mr. Drummond, which will be based upon the large and varied experience obtainable upon the extensive *réseau* of lines which he controls.

The circumstances under which they came about may be briefly referred to. Some two months ago, Mr. Drummond, having determined to settle to his own satisfaction the vexed claims for superiority, put forward by the automatic and the vacuum representatives, gave to each a similar train which was to be equipped in the completest and most perfect manner. After a short time the Westinghouse train was finished and ready for trial, but many delays occurred before the vacuum train was reported in running order. At last, however, it was finished, and invitations were issued to the leading railway men throughout the country. The Westinghouse train was taken out first, and ran from Edinburgh to Cowlairs over about forty miles of very fine line, in first-rate order, and the gradients of which are practically level. Some dozen stops were made in running out, and eighteen more in returning to Edinburgh, where the vacuum train was to be taken out for a first trial.

The vacuum train, however, did not appear. It was stated that the cause of the failure to come to trial was as follows: The representatives of the Vacuum Brake Company had borrowed from the Great Northern Railway two vans containing pumping apparatus to act as auxiliary appliances, and help out the ejector in producing a quick stop. One of these pumps had, it appeared, become, at the last moment, too much deranged to render trial possible, and hot axle-boxes were further reported as justifying delay. The further trial was, therefore, postponed. The vacuum train had a test run, and was reported to be in perfect order the previous Wednesday. The Westinghouse train was made up of nine vehicles, to all the wheels of which, as well as to the engine and tender, brake blocks were fitted. A tenth vehicle formed an exception to this rule. This was an experimental van, in which was placed a table carrying the indicating apparatus, speed guage, &c. On one side of the van was attached an electric signalling instrument, a similar one being placed on the engine, and communication was established between the two. A guage for recording the variations of pressure in the brake pipe was also in the van. As soon as any given speed, previously decided upon, was reached and indicated upon the speed guage, the signal was given through the wire from the van to the engine, the brakes being applied at the same moment that a return signal intimated the fact to the operator in the van. As soon as this return signal was heard, the time taken to bring the train to a stop, was ascertained by a chronoscope, and two diagrams were taken by Richards' indicators adapted for the purpose, the one showing the speed of the train at the moment when the brakes were applied (thus checking the speed gauge), the distance run before the train was stopped, and the retarding influence of the brakes throughout the period of their application. The diagrams taken by the second indicator showed the distance run before the full power of the brake was developed, while the time required for the brakes to be set on at the rear of the train was obtained by a second observer with a chronoscope, who recorded the number of seconds and quarter seconds that elapsed, from the falling of the brake pressure gauge to zero, to the stopping of the train.

Water from the same accumulator as that which actuates the speed-gauge, is in the experimental apparatus on the North British train, employed to work the two Richards' indicators already referred to. The motion for the drums of the latter is taken off the main pulley of the speed indicator, but reduced sufficiently through two worm gears. The ratios of speed between the pulley and the drum being exactly determined, the distance traversed by the train in making a stop can be accurately scaled, while the height above the zero line, at which the diagram terminates, gives also the speed of the train at the moment of applying the brakes, and thus the readings of the speed-gauge can be checked. As already stated, a second indicator forms a part of the experimental apparatus, and is used for taking diagrams to show the distance traversed by the train before the brakes are fully applied. The foregoing gives as clear an idea as it is possible to convey without drawings of the appliances prepared for testing the performances of the automatic and vacuum brakes on the North British Railway.

Their efficiency was thoroughly tested on Tuesday. On the run from Edinburgh to Cowlairs about a dozen stops were made and the results recorded, and eighteen similar experiments were tried on the return journey. Diagrams of each stop were taken, and the whole operation was completed in from twelve to thirty-five seconds, according to the time required to pull up the train. The element of uncertainty arising from misapprehension of distances run, of speeds attained, and so forth, are entirely eliminated, and moreover the character of each brake application is clearly shown in the diagram; so that not only can a great deal more experimental work be got through in a given time, but the results obtained are absolutely reliable, and the relative performances of different brakes can be compared with the utmost minuteness. It should be mentioned, by the way, that the speed-gauge employed on Tuesday recorded velocities slightly in excess of the truth, but this can be easily obviated; indeed the error corrects itself on the diagrams taken.

HOUSE DRAINAGE.

By Major-General F. C. COTTON, C. S. I.

From "Journal of the Society of Arts."

The paper I am about to read is not volunteered by me. It is written in furtherance of the effort now being made by the Society of Arts to elicit information on the subject of house-drainage, and to aid in its promulgation, by which it is hoped that the knowledge of this all-important subject may be made more general, and that this extended knowledge may so enhance the value of houses constructed on right principles, that builders will see the importance of being guided in their work by the teachers of sanitary science. Another result of a more general knowledge of the subject will, our Society hopes, be the enactment of better defined laws for the guidance of those who are entrusted with the public health.

In accepting the duty I have undertaken to-night, I am placing myself in the unfavorable position of addressing at once those who have made the subject of my paper their deepest study, and those who have still to be awakened to its importance, and are in need of the most rudimentary education.

It must, of course, appear to those who have been preaching on the same text for years, that recapitulation of their teaching must be unnecessary. But that this is not the case is proved by the entire disregard of all the first principles of sanitary science shown in the last year, both by the builders and the occupiers of many new houses, and that even in London, from which so much of the teaching emanates.

With this explanation I must crav the indulgence of all the men of sanitary science who are present to-night ; begging them to accept my assurance that I do not presume to offer an education to them. What I hope for from their presence is the criticism that will lead to the correction of my paper. And in addition to that, I ask a full and free discussion of the points touched upon, which cannot but make the evening instructive to both sections of the meeting.

Though I shall limit my remarks to-night to the pipes and drains of a house, without entering into the requirements of the main sewer, I shall not, as the notice of my paper would imply, confine myself to the "construction of house drains." I purpose to submit to the Society such a *résumé* of what has been determined in sanitary science as will be a safe and useful guide to those who, having little or no knowledge of the subject themselves, are, nevertheless, aware that pure air is worth having, and that they would, if they could, obtain it.

This much is generally admitted, but there are comparatively few who realize what is the daily loss of health, and consequently of happiness, even by the well-to-do classes, from breathing contaminated air. Everyone, indeed, is ready to admit that the best remedy for the effect of a town life is an occasional visit to the moors or mountains, where the air is so exhilarating that it gives the idea of containing some stimulating principle not to be found in the air of cities; whereas there is nothing intoxicating in the atmosphere of the most favored regions. It is simply pure, as air ought to be; and so those who breathe it have the health, and vigor, and buoyant spirits that were their birthright.

It is in our houses—more especially in our town houses—that the air is in an abnormal condition, as Dr. May explained the other day to his neighbors at Kensington, who complained of lassitude and debility from the "relaxing climate" of the locality they lived in, that their languor arose from the loss of vital energy, the result of breathing air tainted by gases from their own foul drains.

It is this depressing effect of impure air that accounts for the "nine sinkings" said to be felt by London ladies between their waking hours and bed-time. In this there is no affectation of distress on their part. Follow these ladies in their Highland tour, and you will find them satisfying a healthy appetite by three hearty meals a-day, and craving for nothing more.

And if we watch the effect of these depressing gases on the poorer classes, who can have no change of air at any season, we must follow them to the fatal gin-shop, where, poor souls, they find an exhilaration which seems to them worth having, however evanescent, and however fatal in its after-consequences.

I am induced to insist upon this never-ceasing loss of vigor from impure air, as it comes directly home to everyone at all times; since it appears to me that the reports of occasional visitations from typhoid fever or diphtheria only stagger people for the moment, and being too terrible to dwell upon, they do no more to correct the defects in our sanitary system than public executions did to lessen the amount of crime. In the depression that results from living in an impure air, all our functions are crippled, and we have none of that elasticity to throw off disease which we have when in perfect vigor. Like the weakly plant, the blight can take possession of us unresisted. This is admitted in a way, but it is not fully recognized; or the great effort, both of rich and poor, would be to purchase the purest air that could be bought, according to their means, looking to sanitary laws as the only safeguard in the artificial life they are leading.

There is no doubt that some of our first efforts at refinement did anything but place us in a better sanitary condition, notably the introduction of closed sewers, and the closet in direct communication with them, which led to evils that are still only in progress of correction. Indeed, it is almost exclusively this refinement that affords us the subject we are to discuss to-night. On the other hand, giving them up would throw us back to barbarism.

When the danger arising from this was first looked into early in the century, it became apparent that some alteration was necessary in the sewers, for they carried off the waste so slowly and uncertainly that they virtually distilled the decomposing mass, and returned all that was poisonous in a gaseous form, most difficult to deal with.

We are indebted to Mr. Roe for the first effort to correct this, by altering the form of the sewer, so that a much smaller quantity flowing would have velocity sufficient to keep the passage clear. This was a most important step, and led to what was done immediately afterwards by Mr. Edwin Chadwick, who, realizing fully the danger of allowing the sewage to decompose within reach of inhabited places, devoted his wonderful energy to convince the world that the only safety was in expediting its passage from its source in the house to its outlet in the air, wherever that might be done without fear of further mischief. In his investigations, that great reformer convinced himself that, under a perfect system of drainage, the sewerage of all London might be put out of harm's way before it began to liberate its gases. Whether this was attainable or not, it led to an entire change in our whole drainage system, the importance of which cannot be over-estimated.

I am sure I shall be forgiven if I occupy the meeting for a few moments, while I mention the services rendered by Mr. Edwin Chadwick, who, most unfortunately, is, by a rule of our Society, absent from the Council this year, when one of his own special subjects will be frequently under consideration; and I must at the same time express regret that we are, from the same cause, deprived of the advice in our Council of Mr. Robert Rawlinson, whose guidance would have been invaluable.

Mr. Chadwick was not by profession an engineer, and he had the difficulty to contend with of the country not being educated up to his mark. No Government can go far a-head of the people's education, so our great sanitary reformer was a difficulty to the Ministers of the day. Even the engineers could not take up his views, one eminent man of that profession having been heard to say, in irony, "Chadwick would drain all London through a gun-barrel." And although he brought to bear upon his subject thorough knowledge of it, ability of the highest stamp, and enthusiasm that nothing could curb, he had, unfortunately, to leave many important suggestions to be carried out at a later day. It must, however, be no slight satisfaction to him to find an engineer so pre-eminent in sanitary science as Mr. Robert Rawlinson, dedicating to him, as "the chief promoter of modern sanitary works and appliances," a collection of the most able papers and letters ever published on the subject.

Leaving out of account for the present the effect of sewage soaking into the ground, and contaminating the water we may need to draw upon for our use, all that is poisonous from the sewers comes to us in the shape of gas. This is produced by the organic waste from our houses being decomposed, the decomposition being aided by the addition of water, and expedited by heat, stillness of the air and stagnation of the fluid mass being highly favorable to this chemical process. Of the exact nature of all the gases evolved in this terrible retort we are not yet aware; and when the complication of the seething mass is considered, the variety of its ingredients, and the different proportion in which they are thrown together, its ever varying temperature affecting the liberation and expansion of the several gases, each according to its own laws, it cannot be expected that, even with the high talent engaged in the research, we shall, for some time to come, unravel its mysteries.

If it were necessary that we should master all this difficulty before we took steps to correct the evil, we might well be disheartened in our investigations; but, thanks to those who have watched the effect of these mixed gases, we have evidence enough that all we do to reduce the per-centage of them in the air, is a clear gain to human life and health.

If there are any still left who pride themselves on having found a seeming paradox or puzzle in the calculations of sanitary science, and would have us wait till it is explained, they are turning their talent to a very poor account, and have not much chance of a patient hearing in the present day.

I have said that all we have to fear is in the gaseous state; we cannot prevent decomposition liberating the elements in that form. We must, therefore, do all we can to remove the material from our home as rapidly as possible, by the most suitable means at our disposal, the vehicle for the present used being water; which, although it affords an extremely cheap carriage, and is very convenient for our purpose, is, nevertheless, not without its danger. Water in certain quantities aids in the decomposition of our refuse, and supplies some of the ingredients of the noxious gases that we dread. Great efforts have, therefore, been made to avoid the use of water, and several so-called dry systems have been introduced and tried, in some localities with success; but I need not now enumerate them, as they are foreign to our purpose to-night. We may, however, wish their promoters God-speed, while we make the best of the means now at our disposal, which must, under any circumstance, be in use for many years to come, even though any safer system should eventually be perfected.

I must be allowed to say that there is something very attractive to me in Captain Liernur's idea of everything solid or gaseous being drawn inwards and onwards to a distant vacuum, the solids to be dried and utilized, the rest to be evaporated by fire. But we have nothing to do with this at present; water is our vehicle, and we must so use it that it shall lessen, not increase our danger. To ensure this, the essential is an abundant, and, as far as possible, a constant supply.

We will now consider the appliances by which we turn to account this water-carriage, the most important of which are what are usually called the house-drains, those which collect the discharge from all the pipes and convey it into the sewer. In large houses there are often several of these, but, for convenience of description, I will use the singular number.

In detached houses the house-drain may always be led clear of the building, and possibly no house in future will be placed at the disadvantage of having it under the basement. Many old houses have this fault, some no doubt in consequence of the house having been extended over it. In all such cases it would be well to correct this objectionable arrangement at almost any cost, since the danger of the position is extreme.

In houses built in streets this faulty system constantly prevails. It has been the general practice to have the sewer under the street, and as the offices and all that is unsightly lie at the back, the drain of necessity has to be laid under the house. Where the lines of houses are very near together this is unavoidable, but it raises a question whether in building in future this ought to be allowed.

I am no advocate for tyrannical Government; but I think that when the owner of land has to make his choice, whether he shall continue to cultivate it, or raise a crop of houses on it instead, the Government may fairly insist upon his not building at all, if he will not be guided by sanitary laws; and I would undoubtedly define the minimum distance at which lines of houses should be placed, as well as the disposition of the drainage, on which the sanitary condition of the new street will in the future so materially depend.

We have only to consider the nature of the house-drain, and the evils resulting from its being imperfect, to realize the importance of its not being under the house. This vital artery of the system, having to carry the whole refuse of the house, and deposit it in the sewer, will contain two currents, one of fluid and solid matter descending, and one of sewer gas ascending; for it is a neck of the great retort, and will be supplied with gas from it, do what we will to divert it by ventilators along its course, as is now so generally and so advisably arranged for.

The appliance in most frequent use for this drain is a stoneware pipe, which is made in short lengths, necessitating even in small houses very many joints. If these joints and the junction with the sewer and the house-pipes were water-tight and gas-tight, it would matter nothing whether the drain were under the house or not. But if the material fails from any cause, or a joint is broken, the consequences are an escape of either gas, or sewage, or both, that will in time saturate the soil surrounding it. If this takes place when the pipe is clear of the building, it will be detected, and may be comparatively easily corrected. But if the pipe is below the basement, the first cause of suspicion that all is not right may be in the illness or death of an inmate of the house. And as the pipe cannot be examined without taking up the basement floor, its actual condition will never be inquired into by the occupants of the house, unless they possess an amount of energy very unusual.

Back drainage, as it is called, when the drain from the house leads to a sewer at the back, has other important advantages, besides the accessibility of the drain, and the comparatively little mischief it will cause if it is imperfect. It will, in most cases, be shorter by the whole depth of the house, and consequently have a far more rapid fall, while the whole sewer-system can be opened at any time without interfering with the street traffic. This better mode of laying out building land has been adopted here and there, but there are great towns rising all round London, and, indeed, all over England, where the old mode is continued.

I must notice here the mode insisted on by Mr. Rawlinson of laying out house-drains, where curves have hitherto been used. He would have the whole system in straight lines, with man-holes at all the angles; by which arrangement the drains can be cleared without being broken up. When the length of any line is great, a man-hole will be made at the spots necessary to bring the whole within reach of those engaged in cleansing it.

We will suppose our drains, then, to be under the house, in considering its requirements, and with reference to the size, return to the principle that guided Mr. Chadwick, namely:—That no drain or pipe intended for the passage of water and its burden should be larger than the maximum it will be called on to convey, without being subjected to undue pressure, in order that a favorable velocity and scour might be ensured, and the surface of the pipe kept as clean as possible thereby. The required size for each pipe will be determined by the supply and the fall that can be given to it, experience having led to the conclusion that it is well to make allowance for house-drains not being more than half-filled with their maximum charge, the fact being that even a pipe of six inches internal diameter will carry all the drainage of a tolerably large house. I mention this only to give a general notion of the size, for the actual size in every case should be decided on the spot by a qualified engineer, who would have all the peculiarities of the site before him. In all designs for house-drains it must be considered that, although we have, as compared with the sewer, only feet instead of miles over which to expedite the current, we must not lose sight of the fact that any material which will decompose may find a lodgment in our pipes, if the stream is not rapid enough to lift it and transport it. The first consideration is, how it can be kept clear, even though the supply of water entering it may not be constant. The essentials will be, a fall that will give a good velocity to the current, even when the depth of the flow is small; the most polished surface that can be obtained, and the best fitting joints, not only to prevent escape but to present no obstacle, however small, to the passing current, lest the detained particles should collect others, and so form a reservoir of the sewage, in which, when there happens to be little or no flow in the pipe, decomposition will take place, and a private distillery of poison will be established on the premises.

Glazed stoneware is a good material, as it is not acted upon chemically by the gas or sewage; and its surface being highly polished, and not capable of being corroded, it will offer less resistance to the fluid than would be the case with either lead or iron.

The objection to stoneware is the difficulty of perfecting the joints, and having them so true as to offer no impediment. A vast variety of joints, and all sorts of lute and packing, have been suggested, the practical difficulty being to form a perfectly tight joint which is not so rigid that on the slightest movement of the pipe it would cause the ware to break. To obviate this, pipes are very frequently laid, trusting the safety of the joints to a packing of clay, which, of all the materials in the world is the most treacherous. My experience, in a long life of engineering, is that clay is unfit for anything but the fire; it is admirable in the hands of the potter, but, unburnt, it is utterly untrustworthy. When wet, it is plastic and adhesive; water-tight, pleasant to work, and satisfactory in appearance, but on drying it shrinks and cracks, loses its hold, and its every characteristic is reversed. A house founded on clay may stand any number of years, and settle in a dry summer after all. A clay puddle-bank has been the cause of the most terrible disasters, and as a lute for joints it may be clay one day and powder the next.

As it would be utterly impossible to do justice, in the selection of the best material or appliance, amongst the numberless clever inventions of the day, I had resolved to offer no opinion upon any; but I am inclined to break that resolution, by recommending a pipe which from the form of its joint, and the perfection of its manufacture, I do consider one of the most valuable additions to sanitary appliances ever brought to light. I allude to Mr. Stanford's joints, as they are made by Messrs. Doulton, which from their spherical form admit of some movement without opening; and by the skill with which they are made, are really as perfect as the ground-glass stopper of a phial. It is almost impossible to guard against careless workmanship, but from the rapidity with which these pipes can be laid, and the facility in laying them, particularly where the slope would help to ensure the joints being closed, superintendence of the work is simplified to the utmost, a point of great importance when the sanitary officer, with his many duties, is held responsible.

Whatever pipes are used, they ought to be lodged on concrete, so thick as to secure them against the operations of rats, which never seem to give up the hope that they may undermine a pipe, and when it settles, have access to the luxuries it contains. In the case of pipes being used, the joints of which can not be trusted, I know no way of making them secure, but by imbedding them entirely in concrete. Pipes very inferior to those now used were employed in the old city of Broussa, in Asia Minor, which, thus embedded, bore a great head of water, supplying fountains in every house. Some of these remain in use to the present day.

When laid, this very important pipe is buried in soil of some sort, the floor is closed over it, and nothing more is known of its condition for any length of time. It is fully admitted that, before this is done, the work should have been inspected by some one deputed to report upon it to the Local Board. But it is urged that, where much building is going on, the Boards have not staff enough to watch the work, so as to be able to say confidently, not only that the design is satisfactory, but that the materials are suitable and good of their kind, and the workmanship faithful. Yet the drain, on which so much depends, may entirely fail if in any one of these points a fault may have been detected.

This brings it to a question as to whether we are to look to local government for security, and pay for it by higher rates, or whether we must take the chance of all being safe below us.

Before we leave the drain we must inquire what has been used to cover it. Is it tolerably free from organic matter that may rot and form gases, independent of the sewer, but, nevertheless, unwholesome? Does any one look into this—either public functionary or the would-be occupant? Certainly not the latter; sanitary knowledge has not yet led to that. And yet the value of the house, as a healthy home, in no slight degree depends upon it.

Our object being to elicit information, I would ask here whether there are still low-lying lands being filled up for houses to be built over; and whether the old system of raising the land economically is still adopted, of merely setting up a black board, with the words on it, "Rubbish may be shot here?" Where land is dear, rubbish cheap, and great interests are involved, have we a local government that will see what this rubbish is that is to be built upon, and prohibit the use of all that is dangerous?

The answer to this will, I am sure, differ as much from all parts of England, as the reading of the Local Management Act differs, by the several officers who were good enough to come to our Conference the other day. Even if the Local Boards have not staff enough to watch the building while in progress, they could, I imagine, prevent so radical a sanitary fault as may result from indifference on this point. In the meantime, I can confidently assert that many miles of houses have, even of late, been built, in which sufficient care has not been taken about the material used for filling in. Even the fine beds of gravel have in many places been injured as sites by this; the gravel has been sold, and the sand below it used for the mortar of the house, and anything that came to hand has formed the surroundings of the drain.

It may not be known by those of my hearers who have not examined such matters, to what extent this may affect a house. The fact is, that our walls are sufficiently open in the center to form flues for air or gas, and when our fires are lighted in the winter they act as pumps, and very powerful pumps, to draw the air and all that is in it from below the basement to the attic; with a delivery between the ceiling and the floor of every story, where there is neither plaster nor paper to seal it up. If we have a rotting mass below the basement floor, we have a supply of gas in the best possible position for these pumps to draw from. With reference to this, it would be well if every wall had, what some few are built with, a water-tight and air-tight course a little way above the basement, the intention of which is to prevent the damp from rising,—this would have a very important effect in this respect. Not that this would save the basement floor from inroad of this gas, but it would, in some measure, check its distribution through the house. If such filthy material as we are speaking of is used, a concrete covering of the whole is essential.

Now that we have so many really able and earnest men watching the builders, as mnch as their multifarious duties admit of, we may, I hope, feel confident that nothing so infamous will ever occur again as Dr. Whitmore found in Harley-street, where some thirty house-drains had never been led into the sewer, and had been for years pouring their contents into the soil.

But until some system is adopted that will induce builders to make this critical part of a house secure, we can never consider ourselves sure that we have the air of our rooms free from taint, from some flaw or other.

It will be for future consideration whether an extended supervision by the Local Board, or penalties on the builders for negligence, when discovered, certificates by accredited engineers, or any other better means can be devised. All we can do at present is to urge that the subject may not be dropped till it is thoroughly investigated, and the abuse corrected.

The connection of the pipes supplying the house-drain will be defended to a certain degree by one of the many ingenious traps that have been invented for the purpose, on the merits of which I will not venture an opinion. It is well established, now, that the water in any trap will absorb gas, and, if time is allowed, it will pass through it. It is not, in short, the security it was once supposed to be; but when it is considered that what we are doing is to use every means to divert, exclude, and dilute the gas that is ready to enter the house wherever there is an opening, it is evident that a trap is one of the means not to be neglected where it can have any effect at all, and a well-constructed trap with fresh water passing through it frequently is of very important service, always provided that it does not lead to an accumulation of gas behind it. If it did so, it would do more harm than good, for then, sooner or later, the gas would force its way through in a concentrated and consequently a most poisonous state. Indeed, the whole point seems to turn upon the state of concentration the gas is in; and the sewer engineer is acting on that supposition when he makes an opening every hundred yards, in the hope of the gas escaping in so mild a form that, when mixed with the air, it will be harmless. It would be well if we could ventilate the house-drain as simply, but that would bring us too immediately in contact with the gas, which even in the open street is bad enough at times.

Where the house-drain can be continued to a higher point above the last connection with it, as is sometimes the case on a hill-side, an outlet may be made there for its ventilation on the level of the ground, if there is nothing to be injured by it. But in town houses the highest point or head of the drain will be where the highest pipe from the house enters it. And here the gas must be allowed to escape by a tube carried high up the roof, away from either attic, window, or chimney, lest a draught should draw it into either. If gas would take advantage of such an outlet, and rush up it rapidly at all times, ventilation of the drain by that means would be simple enough, but gas has no such accomodating tendency. It has the peculiar faculty of diffusing itself through the air and within other gases, but it seems to keep its cloud form when not under pressure, and to move with a rotatory motion, a remarkable illustration of which is seen in the cloud-form adopted by steam as soon as it is clear of the funnel of the locomotive.

Without going into the complex nature of gases, of which I am quite incompetent, I only allude to these peculiarities to give some idea of the slow progress gas might be expected to make in diffusing itself along a thin pipe, from which we see the advantage to be derived by the use of a tube of large diameter in ventilation. When the air is at rest, and there is no difference of pressure between that in the sewer and that at the head of the pipe, we shall only have the advantage of this diffusion, greater or less, according to temperature. But anything that alters the pressure in the sewer or drain, will cause another movement in the gas. A sudden gust of wind, entering by the sewer ventilator, may clear the whole pipe in a moment; and if the drain become warmer than the air, there will be a current established upwards. A passing wind across the head of the pipe is found to draw the air or gas out more rapidly; in short, the gas will always be moving in the tube, sometimes very rapidly, and the tendency will generally be in favor of an upward current. We have, therefore, in a simple pipe, a great auxiliary in our effort to get the gas away. A ventilator in that position should never be omitted, and in no case could a pipe of less diameter than four inches, be trusted. Many suggestions have been made to insure a good upward draught in the pipe, which I shall not discuss here, merely saying that it is the object to be sought for.

We will continue our consideration of the house-drainage system above the floor of the basement. It is thoroughly established that no pipe in the house should be actually connected with the house-drain excepting the soil-pipe, which carries all that cannot be delivered in the open-air without offence. The rain-water, the waste from the several sinks and from the baths, can all be discharged into the open air, and be led into a grating with traps below them; they should on no account have a direct communication with the drain. It would seem impossible to many of you that any mention of this very obvious fact should require further notice; but I can assure you that if you will look into hundreds of houses close at hand, you will find that the builders of them are altogether ignorant of this. I say ignorant, because there can be no earthly reason why they should not act upon the knowledge, if they possessed it, seeing that the change from the old system to the new, would not, in this particular, cost a shilling more in the building of a house of any size.

The pipes from all other sources than the scullery, flowing into the open grating, will be rather a gain to the house-drain, helping to scour it, but the scullery supply will be loaded with grease, which, when it chills, is difficult to deal with, and it would be well if it could be all deposited before it reaches the drain. Many clever devices have been invented to effect this, but none of them can be left to take care of themselves. If the grease is caught, as it ought to be, it must be removed by hand, or the drain will become foul and offensive, and be the cause of mischief. It is recommended that a stream of hot water should be turned into the drain occasionally, to melt any grease that may adhere to it; but if this is done, the sudden increase of heat will cause the gas to expand, with every probability of its forcing the trap above; while the grease will only be carried into the drain, and there be deposited out of reach. The clearing of the scullery-pipe, and the prevention as far as possible of grease in the house-drain, should never be overlooked.

All the waste from the baths and such like may be turned into the rain-water pipes, which may be of iron, and so that they keep the water from making the wall damp, and end about a foot from the ground; they require no special attention. In the country this arrangement will, of course, be modified where it is an object to save the rain water; and it would also be necessary in London, if the water did not contain so much that is objectionable.

The chief anxiety of the house system will be the soil-pipes, and the fewer there are of them the better. The soil-pipe should never be closed at the top, it should be extended upwards, whether over the roof or through the roof at its full size, and terminate, like the other ventilator, where its discharge of gas can do no harm. It will, under this arrangement, be a permanent ventilation, and an occasional waste-pipe; and although gas would be held in it in a very diluted state, still its condition depends upon so many influences, that it must always be considered dangerous. If no water has passed through the trap in the house drain for some time, it may be receiving a heavy charge from that source; there may be fumes from its own unclean state, or from gases generated in the traps that are in each closet drain that joins it, which will rarely be filled with quite clean water. This pipe ought not to be made of lead, if a better material can be found, because the gas acts upon and destroys it rapidly. If it is of lead, as it very generally is, it ought to be made without solder, as that is still more rapidly acted upon by the gas. A good lead pipe, however, will last a long time, and if outside the house, its condition can be watched. Stone-ware can be used when built into the wall, and if Stanford's joints are employed ought to be secure. There will be no soil-pipe inside the house when architects have completed the study of sanitary science.

Where the branch from a water-closet joins the soil-pipe there will be a trap; the pan itself forming another trap, there will then be that greatest of dangers in any system of drains, a space enclosed between two traps, in which gas may become concentrated to any amount. There is little doubt that gas has been collected in these spaces that has been most fatal. I was told of a case the other day, where a housemaid, opening a valve that had been closed for some time, became insensible from the load of gas that was discharged from it. The quantity of gas generated in this space from moment to moment is very small, and it is only essential that it should have an outlet to the air. In case of its opening near a window, a short length of pipe may be required, but this will not usually be needed, excepting when the closet is away from an outer wall.

It will be seen, as I said when speaking of our house-drainage system, that the whole and sole cause of the danger of concentrated gas entering our houses is from the use of the water-closet.

Their position in a house ought, therefore, to have the architect's greatest consideration. These closets should either be projections or towers, cut off from the house, or failing the possibility of that, close to an outer wall, without which neither the light nor the ventilation essential to their purification can be obtained. It will be well to remember that, if the closet is hotter than the outer air, the tendency will be for the gas in the soil-pipe to force the trap when the valve is opened. In winter there must be a difference of temperature; but I mention the fact to show the advisability of not allowing the closet to be more heated than is absolutely required.

Having done all in our power to exclude sewer gas from our houses, we have still to purify the air of the rooms we are living in, by draining off that which has been vitiated by our own exhalations, and by the combustion which produces artificial light and heat. The air that has been injured by these causes is unfit for respiration, till it has been restored to a sufficient degree of purity by the admixture of fresh air, which, of course, implies a constant current of air out of the chamber to make room for the fresh supply.

The quantity of air polluted by each individual breathing, and the quantity demanded for illumination and heating, have, of course, all been tabulated, and tests determining the most minute quantities have been brought to bear upon the investigation, one result of which is to show that the chemical difference betwixt pure air and air unfit for respiration is very small in amount, showing how necessary a constant change must be. Dr. Angus Smith gives the difference of only three per cent. of oxygen in pure air and in air that is unwholesome, while the quantity we require in an hour is said to be 3,000 cubic feet for a single individual. I need not go further into quantities to make my hearers wonder how we can find air enough to breathe in crowded and brilliantly-lighted rooms in winter, when there is no apparent inlet.

In summer, when the windows can be opened, we trust to an incessant diffusion from without, and to the almost constant motion in the air from changes of temperature, near or distant. But in winter, when our rooms have to be kept warmer than the outer air, we at once meet with a difficulty in obtaining the current into the room, without producing a chilling stream, undeniably dangerous to health. This danger being more palpable and instantaneous in its effects than the ills arising from breathing tainted air, induces us to take all possible means for preventing it. The door is surrounded with india-rubber, and there are sand-bags on the window-sills, but still the fire burns brightly, and the air is rushing up the chimney; it must come in from somewhere, and in large quantities too. It would be well if we took more trouble to inquire from whence it is supplied. It must enter, for the most part, by crevices in the floor, and inlets so small that they are not observable; indeed it has been demonstrated that air can find its way through the ordinary stock brick with very little pressure. The sources are as various as the directions in which the currents flow; this only being certain, that what does not come almost directly from the outer air is more or less impure.

Mr. Rawlinson says of air brought through flues, "it has the life taken out of it;" then what of air that has been brought by our fires from below the basement through the intricacies of an imperfect wall, and has expanded between the floor and the ceiling of the room below, loaded as that space usually is with chips and bits of plaster, cobwebs, and dust of all sorts? These are as bad flues as air can pass through, and there can be but "little life left in it" when it reaches us.

Even though the house-drain may have been well covered, and decomposing rubbish has not poisoned it at its source, as will frequently have been the case, those who do not so persistently close every possible entrance for fresh air, may still rest assured that in the winter, when every door and window is shut, a good deal of air in their rooms must come from sources that make it very impure before they breathe it. The question of course is, how fresh air, cold as it is in winter, can best be brought into the room without flowing in chill streams upon its occupants. Numberless inventors have worked for this end; among the best results has been the

Galton stove, which seems to me admirably adapted to its purpose. The outer air is led around this stove in such a way that it is warmed and not burnt, and though it enters the room near the ceiling horizontally, it does not, on account of its warmth, begin to fall immediately, as it would if it were cold. Its passage has been traced, and it is found to circulate in the upper part of the room, descending gradually as the fire abstracts the lower stratum, giving the inmates the benefit, before the fire withdraws it from the room. This stove must also be economical in fuel, as much of the heat that would be lost up the chimney, in an ordinary fire-place, is utilized in warming the air that enters the room. But a Galton stove is not at the command of everyone, and we want relief for millions who are living in semi-suffocation.

This, I think, we have in the mode of ventilation brought last year to notice by Mr. Tobin, which was to let the cold air enter by a vertical current, so that it should not fall into the room till it had diffused through the upper stratum. If this principle is correct, it is, I maintain, of extreme importance, because it can be applied at once, by means the most simple and inexpensive, while its use may be extended to buildings of any size.

To show how this suggestion can be utilized at once, I need only refer to General Scott's mode of supplying fresh air to his children's school room. He bored a line of holes in the door of the room, and turned the current upwards by a guard in front of them, by which simple means he obtained the vertical current required. No draught was felt, the air became warmed in the upper part of the room, and eventually was drawn from the floor-level up the chimney. I would ask how many stuffy village schoolrooms there are, that might be changed from being insufferable to sufferable by this simple means?

In a room close to the one we are in, an appliance even more simple has been in use for some time, with very good effect; the lower frame of the upper window-sash being cut, so as to allow the air to come in between the frames, where it takes a vertical course long enough to prevent its falling in a cold stream upon the heads of the inmates of the room, as cold air does when it comes at an angle and falls by gravity. This upward current arises from a similar cause that keeps up a fountain's play, and the extent of its action depends in both cases on the velocity of the stream, at its exit from the orifice for its escape.

There are many other simple ways of treating windows to induce this current, and many more will be suggested when the principle is understood. But I must refer to an admirable trial that has been made of the principle in a ward of St. George's Hospital, by Mr. Brudenell Carter, which has been in use for more than a year. The air is let into the ward by perpendicular tubes, supplied by horizontal tubes open to the air. The upright tubes open above the heads of the patients, who feel nothing of the cold air, though it enters very near them. At the time I had an opportunity of examining the ward, there was a fire in the room, and the thermometer stood at 68° at all heights, from the floor to the ceiling. The air was strikingly pure compared with that of the next ward of the same size and character, but not so treated. Indeed no one could pass from one ward to the other without feeling that it was a complete success. As this ventilation has now had a good trial, I wrote to ask Mr. Carter, whether he was still satisfied with it. His reply was this:—"I am still entirely satisfied with the ventilation, both at St. George's and at home. Nothing could answer more admirably: and I have had its application in my own house considerably extended."

To have this ventilation in perfection, it is evidently necessary that there shall be such a current from the room as will ensure a considerable velocity in the stream entering. With a fire in the room this can be ensured, by stopping in the usual way other entrances that would cause draughts; but it is a question how this can be done, when there is no fire to induce a current. If the chimney flue is open, as it ought always to be, there will be an upward current, as the room becomes warmer than the outer air, and to this extent the system will work automatically when the room is inhabited; but whether the volume entering will always be sufficient under these circumstances I am not prepared to say. Mr. Brudenell Carter, however, finds no fault with the ventilation at any season; at all events, as it now stands, it is undoubtedly valuable when most wanted, *i.e.*, in winter. On its first being brought to notice, it was asserted that all the cold air coming in did not reduce the temperature of the room, an assertion which led, at the moment, to a doubt being thrown on the whole suggestion. But it appeared that, as the loss of heat was entirely in the upper part of the room, where the air would have been over-heated, there was no loss to those who occupied the ward. Indeed, the thermometer standing so high as 68°, with only one fire in the room, went far to prove there would be no reduction in the mean temperature.

What I would ask of this meeting on this head is, that some means should be suggested for causing a sufficient current out of the room at the floor-level, to induce a rapid supply through the tubes when there is no fire in the grate to ensure. When that is established, this system will be made as perfect in summer as it now is in winter.

One great fault found with all currents brought from the outer air in London and other large towns is, that it brings in soot and dirt; and an undeniable objection this is, so objectionable that I am induced to notice what I consider by far the best suggestion yet made to cure this evil. I allude to the arrangement shown in this diagram, in which the air entering is made to impinge on the surface of a tray of water, which, as it becomes loaded, can be emptied and replenished, a most important step, I think, in the growth of this system, which I cannot but hope will be of very general use when once thoroughly understood.

As we have ample reasons at all times to exclude sewer gas from our homes, I have not yet alluded to it in its most formidable character, as a nursery and vehicle for those fatal diseases which are classed as preventible, and well-known now as dirt diseases. The arrangement of the drains and pipes ought, if thoroughly carried out, to secure each house from its own impurities; but such is the character of some of these diseases that your own vigilance will not protect you against your neighbor's negligence. And a most important question rises, as to how those who have set their own house in order can be secured against the ignorance or apathy of those surrounding them. The law of the land ought to save a man from being drugged by poison brewed for him by anyone. Are there such laws in existence now as will protect him? It would appear from the various opinions given by the Officers of Health who attended our Conference, that the Acts of Parliament on which the public health depends, are capable of different readings by those for whose guidance they were passed. But before we go into the administrative, let us see what good results we can claim from our sanitary laws in the condition of the many lines of houses now being built in the extension of London. It is almost universally admitted by the local officers that, although the house-drains are nominally laid under supervision, the staff of the vestries is not strong enough to admit of the work being actually watched. In other words, no man can feel secure that his chief drain is not leaking, and forming a cesspool under his house. This fault may exist in one or all of these new houses. I will now enumerate others actually in sight.

There are two rain-water-pipes, both of which join the drain, with the nominal protection of a trap at the head of it, which has no ventilation. All the other waste-pipes of the house join either the soil-pipe or the drain. It will be observed that there is not an absence of ventilation in this system above the head of the house-drain; on the contrary, there is a passage for sewer-gas into all parts of the house by every pipe. And as the rain-water-pipe and the soil-pipe are of iron with open joints, what does not escape at their head, just on a level with the attic windows, steams from the joints around the windows of the rooms below; while the space beneath the pan of the water-closet, the trap connecting it with the soil-pipe, is left unventilated, a most fruitful source of danger. This list of faults does not, I fear, leave us much to show as good resulting yet from sanitary teaching.

There is one danger from sewer-gas almost more to be dreaded than any other. Its getting into the cisterns, where, from the tendency of water to absorb gas, it will become impregnated and poisonous, owing to the waste-pipes from cisterns being in communication with the drain. This was a very common fault formerly, but is being rapidly corrected now, and sanitary supervision, may, I think, claim its having arrested this most certain cause of danger.

Our sanitary laws are also doing much to correct the water-supply; but where the water is obtained from wells in towns or near buildings, there is always the risk of contamination from leaks in the drains and sewers. Where this is the case, the effects are often fatal. The distance to which the poison may be conveyed was shown in the effect produced on wells supposed to supply the purest water to country houses, when, during the spread of the cattle-plague, the carbolic acid and other pungent disinfectants used in farm buildings near could be detected in the drinking-water. One case came under my own cognisance, where so much store was set by the water of a certain celebrated pump that glass pipes were used to insure its virgin purity, the strong carbolic taste proved that it must always have drawn upon the cattle-sheds for a part of its supply.

Although very much more interest is taken in sanitary subjects than formerly, and numbers of extremely able men are making a study of the science, and giving their knowledge to the world, still the new light has not reached our builders, or, I fear I may add, many of our architects; nor are the existing laws so carried out by pains and penalties as to enforce their learning. Houses in hundreds are still being built, in which every sanitary law is violated. The real remedy for this is, of course, sanitary education; but it must reach the point of being possessed by the public generally before it will affect the builders. As soon as houses are valued for the care taken to insure their healthiness, then only will the builders' attention be diverted from the decorations to the drains. This education ought to be proceeding rapidly, as hardly a day passes that volumes are not published on the subject from the ablest pens. Not only are our first engineers engaged in this teaching, but to their honor be it said, no class in England are more active or more earnest in the work than the medical profession. And as they carry their knowledge from door to door, and enforce their teaching with authority, we may look to them in no slight degree for the people's education. Their efforts, supplemented by letters in the papers, lectures, and the advertising sheets of new appliances—one great disseminator of such knowledge—are all, no doubt, contributing to form this education.

THE APPLICATIONS OF ELECTRICITY TO THE PROTECTION OF LIFE ON RAILWAYS.

By WILLIAM HENRY PREECE, Esq., M. R. I. M. Inst., C. E.

Proceedings of the Royal Institution.

It is proposed in the following discourse to establish three propositions, viz.:

1st. That railway traveling is dangerous.

2d. That railway traveling is safe.

3d. That the danger is potential, and the safety actual; and that the one has been converted into the other by the operations of scientific thought, and by the applications of scientific skill.

1. The first proposition is self-evident, and scarcely needs proof. No one has stood upon a station platform when an express train has rushed madly by without feeling that there was but a rivet, a bolt, or a rod between life and death. A broken tyre or rail would hurl dozens into eternity; a disordered permanent way would maim hundreds; the mistaken motion of a handle, the failure of a signal, or the transmission of erroneous instructions, would spread terror throughout the land. There is no sensation so great as that of a dreadful railway acci-

dent. It affects every one. All are travelers by railway, and natural selfishness makes us read with horror and dismay of the death of *units* in a railway train, while we pursue our breakfast with comparative calmness during the recital of *hundreds* smothered to death in a colliery explosion, or sent to eternity in a watery grave.

2. But is not the fact that, though we have just read the harrowing accounts of a dreadful collision in the north, we instantly entrust our precious bodies in a railway carriage to the south, a proof that there is also safety in railway traveling? Have we not faith in our railway managers, and is not this faith evidence of safety? How many of those present have been in an accident? But, after all, ideas of safety are but relative. Compare accidents on railways with accidents in the old coaching days. Take the loss of life at sea, the accidents in the hunting field, in boating, in bathing, by lightning, etc., and compare them with those on railways.

In 1873, 17,246 persons met with violent deaths in England and Wales, which is an average of 750 per million, or 1 in 1,354. The causes of these deaths are thus analyzed:

TABLE I.—VIOLENT DEATHS IN ENGLAND AND WALES FOR THE YEAR 1873.

Cause of Death.	No.
Injuries in mines	990
Mechanical injuries (not on railways or in mines)	6070
Chemical injuries	2784
Asphyxia	5193
Violence (unclassified)	919
Railways	1290

(*See Tables II and III next column.*)

This, however, is not the death-roll from all causes on all railways of the United Kingdom during the year 1874. The total number of persons recorded at the Board of Trade as having been killed was 1,424. Of these, 211 were passengers, and, of the remainder, 788 were officers or servants of the railway companies, or of contractors, and 425 were trespassers, or suicides, or others who met with accidents at level crossings or from miscellaneous causes.

Some of these may be further analyzed as follows:

TABLE II.—ANALYSIS OF TABLE I.

Cause of Death.	No.
Mechanical Injuries.	
Fall from scaffold (ladder)	165
Fall from window	70
Fall downstairs	456
Fall in ships and boats	134
Fall from height	500
Fall in walking	93
Fall (not stated how)	530
Fall of heavy substances on	509
Horse or other animals	269
Horse conveyance	1250
Machinery	1132
Fight	5
Blow, &c	124
Gunshot wounds	185
Chemical Injuries.	
Burns	1064
Scalds	701
Scalds (drinking hot water)	50
Lightning	21
Sunstroke	96
Exposure to cold	138
Asphyxia.	
Drowned	3232
Suffocated by food	94
Suffocated by bedclothes	611
Hanged, strangled and executed	581
Murder, manslaughter and suicide	228

Let us take accidents to railway passengers from causes within, and beyond, their own control:

TABLE III.—ACCIDENTS TO RAILWAY PASSENGERS, from Causes within and beyond their own Control.

Date.	Within own Control.	Beyond own Control.	Total.
1871	45	12	57
1872	127	24	151
1873	120	40	160
1874	125	86	211
Average	104	41	145

This is an average of forty-one persons killed annually from causes beyond their own control, and it shows, in fact, that the railway companies are in reality more mindful of the lives of their passengers than the passengers are of their own lives.

These latter accidents can be classified as follows:

Table IV.—Accidents to Railway Passengers in 1874, from Causes within their own Control.

Cause of Accident.	No.
From falling between carriages and platforms........................	49
Getting out off or into trains in motion	22
Crossing the line at stations..........	33
Falling down stairs at stations.......	2
Falling out of carriages during traveling of trains......................	9
Other accidents....................	10
Total..................	125

1874 was, however, a very exceptional year, for no less than 71 passengers were killed in the three fearful accidents on the Great Western at Shipton, on the Great Eastern at Thorpe, and on the North British at Browness Junction. Taking the following periods, the proportion of passengers killed from causes beyond their own control to passenger journeys made was:

Table V.—Proportion of Passengers Killed to Journeys Made.

3 y'rs ending 1849, 1 in 4,782,188 j'rneys made.
4 " 1859, 1 " 8,708,411 "
4 " 1869, 1 "12,941,170 "
3 " 1873, 1 "20,089,660 "

Taking the average length of each journey at ten miles, one passenger is killed, from causes beyond his own control, for every 200,896,000 miles traveled. If a person traveled ten hours a day, at the rate of thirty miles an hour for each of the 365 days of the year, he would probably be killed in 1,835 years. Hence, in a relative sense, we may consider that railway traveling is safe.

3. How is this potentiality of danger converted into comparative actuality of safety? Freedom from accident depends upon the perfection of the road, of the rolling stock, of the signals, and, above all, of the men. But none of these elements are perfect. Accidents have been analyzed into—

Table VI.—Percentage Analysis of Railway Accidents.

Defective permanent way....18 per cent.
" rolling stock.......13 "
" signals............28 "
" human machinery..41 "

They have also been classified as follows:

1870.	1871.	1872.	1873.	1874.	Nature of Accident.
9	19	21	24	18	From engines or vehicles meeting with, or leaving the rails in consequence of obstructions, or from defects in connection with the permanent way or works.
10	22	17	23	13	From boiler explosions, failures of axles, wheels, tires, or from other defects in the rolling stock.
..	2	7	5	..	From trains entering stations at too great speed.
61	9	22	18	9	From collisions between engines and trains following one another on the same line of rails, excepting at junctions, stations, or sidings.
18	19	32	20	22	From collisions at junctions.
Included in the above 61	63	91	98	75	From collisions within fixed signals at stations or sidings, &c.
3	2	5	3	6	From collisions between trains, &c., meeting in opposite directions.
1	..	..	3	1	From collisions at level crossings of two railways.
14	12	34	36	17	From passenger trains being wrongly run or turned into sidings, or otherwise through facing points.
6	11	9	11	7	On inclines.
9	12	8	6	..	Miscellaneous.
131	171	246	247	168	

Zeal and anxiety, the necessary evils of a state of tension due to increasing traffic; want of punctuality; late arrivals of the public; and variable weather, become an absolute source of danger. Every accident is traceable to its cause.

Purely inexplicable accidents are unknown. Hence, though considerable improvements in the mode of working have been made—as are indicated in the continued progressive increase shown in the ratio of killed to journeys made in Table V—further improvements are certain. But all improvements bring their own evils, and the greatest of these is human fallibility. The body will tire, and the brain will get out of gear. Pure wilfulness, carelessness, or mischief, are extremely rare. Who does not make a mistake? In the year 1874, 4,400,000 letters out of 967,000,000, or one in 220, found their way to the Returned Letter Office. 89,540 undelivered letters contained valuables, and bank-notes, bills, etc., the value of which alone amounted to £565,000; 337 of these had no addresses; 61,000 postage stamps were found loose in the different post-offices, and 20,000 letters were posted without any address at all.

How then is the comparative safety of railway traveling produced? By taking advantage of the lessons taught by experience, and by applying the means suggested by scientific thought and inventive skill to remedy defects. Failure has thus led to improvement. Every accident has been a lesson learnt, and bitterly have those suffered who have not profited by such writings on the wall. The particulars evidenced by each accident have been carefully and systematically recorded in the reports of the inspecting officers of the Board of Trade, and thus by recording past experience, the materials are collected for carefully generalizing the laws of railway-working, and for establishing a true science of steam locomotion.

Telegraphy, or the art of conveying information by certain pre-concerted signals to the ear and to the eye, is the chief aid of the railway engineer. Thus, at every railway station, level crossing, or junction, signal-posts are erected, which convey to the approaching engine-driver by exposing discs, bars, or semaphore arms in different positions by day, or lamps displaying different colors by night, the fact that the line is clear for him to proceed, or obstructed so that he must stop. The favorite signal by day—the survival of the fittest—is the arm, which, when at right angles, implies *danger*, and when at an angle of 45°, *safety*, and

> "White means right: red means wrong:
> Green means slowly go along,"

teaches the young railway lad the rule of the road by night. The character of every train is indicated by its *head-lights* and its presence to an approaching train by its *tail-lamps.* Should thick weather prevent the sight of the signals, detonating fog signals announce the contiguity of danger. The marshalling of trains in station yards and platforms is produced by whistles and flags by day and lamps by night, all forming a species of telegraphic language between the fixed station and the moving train.

Where telegraphy is required to reach distances beyond the sphere of the ear or the eye, electricity is employed, and the electric telegraph becomes of prime and essential use, not only in regulating the traffic on double and single lines, but in securing safety. Special trains are moved about by its means, delays are remedied, breaks-down rendered harmless, runaway engines have been overtaken by its aid, passengers' luggage recovered, but, above all, irregularities are by its means rapidly announced, and the evils of unpunctuality rendered innocuous.

The greatest element of safety on railways is, however, the Block System.

The block system arose out of the multiplication of trains, and the necessity for increased speed. Necessity the mother of invention, brought it into existence.

By it trains traveling upon the same line of rails are kept apart by a certain and invariable interval of *space,* instead of by an uncertain and variable interval of *time.*

The practice under the time system is to exhibit the danger signal for five minutes, and the caution signal for five minutes more, after a train or engine has been despatched from or past any station, junction, level crossing, or siding. Trains are thus said to be kept apart by fixed periods of five minutes, and if the caution signals were properly regarded, by an interval of time even longer than that. The safety of the train is entirely the responsibility of the driver. Immunity from accident is dependent upon his keeping a clear look-out. If engines ran at regular and fixed speeds, if time tables could be adhered to, if the line were not crowded with traffic, if the driver could always ensure a good view before him, if signals were near together and they were properly regarded, then a rigid interval of time might be maintained between following trains; but none of these elements of safety are constant. Fast expresses follow slow goods trains, now through a thick fog, now up a wet incline, at one moment in bright sunshine, at the next in a thick snowstorm; creeping mineral trains break down in a long interval between two stations; passengers rush in at the very last minute, detain the train, and prevent the time tables from being adhered to; trains are so frequent at some places that the five minutes' interval cannot be adhered to; obstructions to view arise from curves or cuttings, or from atmospheric causes; long lengths of line are unprotected by any signal at all, and signals themselves are too frequently neglected. Hence, the system is brimful of elements of danger, and the inexorable logic of facts has shown that the time interval is illusory and the system unsafe.

But when trains, however rapidly or slowly they may be running, however much punctuality has been infringed, however crowded with traffic the line may be, are invariably kept apart by an interval of one or two miles, collision between them becomes impossible. This is the *Block System*, which has, very improperly, been divided into two classes, the *absolute*, and the *permissive*. The former is the block system proper, the latter is not a "block" system at all, but a system introduced, not to secure the safety of trains, but to increase the capacity of the line for the transmission of increasing traffic. It is, doubtless, an improvement on the time system, but it bears little affinity to the block, and should certainly not be included in the same category.

The block system is effectually carried out by means of electricity. Communication is maintained between station and station by means of bells rung by currents sent to announce the approach and departure of the trains. Permanent signals are raised and lowered, indices are moved to one position or another to indicate the presence or absence of danger, or the fact of the line being obstructed or clear. Indicators are moved to repeat back the signals made to check accuracy in working, and to render futile the errors or carelessness of the hasty or thoughtless. Safety is secured and accuracy in working is maintained by checks and by counterchecks.

The block system on single lines is additionally used to protect trains from *advancing* as well as from *succeeding* trains. Before a train is allowed to leave A the line at B is blocked in advance, and when it leaves it is blocked behind at A, so that it is thoroughly protected in both directions during the period it is running from A to B.

But apart from the protection which electricity imparts to railway traveling, and the facility it offers for adjusting and regulating the traffic, there are innumerable purposes for which the telegraph is employed to facilitate business and to secure efficiency. The distribution of correct time, the collection of spare trucks and coaches, the relief of staff, the supply of assistance in cases of accident and danger, and—not least—the reparation of the error and thoughtlessness of passengers.

It is used on some lines to establish an effective means of communication between passenger and guard; and perhaps one of its most useful applications is to record in the signal-box, before the signal-man's eyes, the position of the signal arm by day and the condition of light by night, which is hidden from his sight by the formation of the line, buildings, darkness, fog, or steam. Electric repeaters are of the greatest elements of safety in working railways.

The operation of scientific thought has introduced many mechanical elements of safety into railway working, which are as ingenious as they are effective.

Improved permanent way, the interlocking of signals and points; the concentration of levers in well-constructed cabins; effective break power; perfect tyre fastenings; better coupling arrangements, and superior engine and rolling stock, have all aided to secure that simplicity in working and safety in traveling which undoubtedly exist.

But, as the principal element of danger

in railway traveling consists in the fallibility of the human machine, it must not be forgotten that we owe our immunity from accident as much to the careful selection, education, and supervision of the staff and the maintenance of good discipline, as to the appliances of scientific skill. Science cannot be devoted to a nobler purpose than to the protection of human life, and the records of experience show that it has earned well-deserved laurels in rendering the dangers of railway traveling potential and its safety actual.

EXPERIMENTS WITH WATER METERS AT WIESBADEN.

By C. MUCHALL.

From "Journal für Gasbeleuchtung."

After commenting on the great importance of water-meters for German towns, the Author points out the practical results from the trials of a large number of meters, in contradistinction to many experiments, lately published, with a single instrument of one particular system, which are almost useless, as they do not indicate how the meter acts in practice, to what accidents it is liable, and what is the cost of maintenance and repair, questions which can only be settled by long experience, but on which much of the accuracy depends. Although that meter is preferable which measures most accurately and the smallest quantities, no system of meters can ever come into general use in which the cost of fixing, maintenance, and repairs is large.

The four systems of water-meters used were those of Kennedy, Frost, Siemens, and Taylor, the two former being piston meters, and the two latter wheel meters.

The numbers of each on the 31st December, 1875, were as follows:

Calibre.	⅜ inch.	½ inch.	¾ inch.	1 inch.	1½ inch.	2 inch.	4 inch.	Total.
Kennedy	42	53	7	8	..	..	..	110
Frost	21	3	..	..	..	..	..	24
Siemens	11	258	886	36	5	3	1	1,200
Tylor	..	152	158	..	..	..	..	310
	74	466	1,051	44	5	3	1	1,644

The points to be taken into consideration were: 1. Degree of accuracy of the meter; 2. Duration of the initial accuracy; 3. Frequency of repairs; 4. Facility of fixing and removal; 5. Cost of purchase and maintenance.

Those of Kennedy and Frost were found to be most accurate; that of Tylor generally registered two to three pints per minute, while the Siemens meter would with a small flow either not register at all, or only very slightly.

Each meter was tried, before being used, with a Kennedy and a Frost meter known to be correct, and from time to time gauged by a measuring vessel of known contents. Both the entry and the outflow pipes were provided with cocks, that of the former being always wide open, to have the full pressure on the meter.

The outflow cock served to regulate the volume of water which flowed through. The trials were usually carried out by allowing 1,100 gallons to flow through in quantities varying from seven to thirty-five pints per minute. If the differences at the end of the trial were greater than ± 3 or 4 per cent., the meter in question was adjusted and tested as before. This adjustment only took place with the wheel meters, as the piston meters always registered correctly when the piston was properly packed. The adjustment was effected either by slightly extending the blades of the fan, so as to make them travel more quickly, or by filing them down to diminish their speed, or else a counter stream was more or less increased, for which purpose the Tylor meter is provided with a set-screw, whereas the Siemens meter must be taken to pieces in order to be adjusted. It was found, however, that the latter adjustment was not accurate, as the influence of the counter stream on different volumes of water, passing through in the same time, was not the same.

The duration of the initial accuracy depends chiefly on the construction. The Frost and Kennedy meters registered accurately only so long as the piston packing and gearing were perfect. Kennedy meters were often found inaccurate on account of the india-rubber ring becoming concave. In this respect the wheel meters are to be preferred. It was found, especially of the Siemens meters which have been several years in use, that some show as much as twenty per cent. plus, and others a considerable minus. In both cases the variation may be attributed to rust, deposited either on the blades of the fan or on the axle. In the first instance this would increase both the surface of the fan-blade and its mass, and thereby have a tendency to increase its velocity, especially in the case of an irregular flow; whilst, if the rust is on the axle, the increased friction on the bearings would diminish the speed. It was also found that the same meter, after it had been cleaned from rust, registered less if the rust had been on the blades, but more if it was removed from the axle. Tylor meters, which did not exhibit similar inaccuracy, were also quite free from rust, so that meters whose casing consists of brass must be preferred to those of iron.

With regard to the frequency of repair, this is usually necessitated by their ceasing to work, but occasionally by leakages, illegibility of the dial, or damages. The latter causes are comparatively rare, and can never be totally avoided, but it is different when a meter stops working, which is essentially caused by a fault of construction. It appeared that Kennedy meters ceased to register when either the stuffing-box of the piston-rod or that of the valve-rod (steuerrungshahn) was tightened too much, or when the packing became hard and dry. With the heavy pressure, sometimes $8\frac{1}{2}$ atmospheres, this cannot always be avoided. It also failed when the india-rubber ring, which rolls up and down on the piston, got twisted or broken.

Of all the meters observed, those of Frost stuck most easily, as the complicated gearing, which is in the water, is soon covered with slime and ceases to work. As all stagnant water deposits slime, however slightly, the frequent stopping of this meter is a great evil, and it is rendered the more inconvenient because the meter, when fast, does not permit the water to pass.

In Siemens meters the cause of stoppage is usually slime and rust, either on the axle or on the wheel, or else deposited between the wheel and the casing.

With Tylor meters there have been several instances in which two or more of the fans have been broken off the wheel. This is partly caused by the brittleness of the metal of which they were made (since replaced by tougher metal), but more frequently by the presence of foreign substances, such as small pieces of lead or tin too fine for the meshes of the sieve, which caused the fan-wheel to jam, generally the result of careless soldering and repair; these may be kept back by the sieve for a long time, and though not bigger than the head of a small pin, may at length suffice to stop the meter.

Of the sixteen hundred and forty-four meters fixed up to the end of 1875, one hundred and ninety-five stuck in the course of that year. They were—

(*See Table on following page.*)

All these had to be taken out excepting the majority of the Kennedy meters, in which the gearing had become clogged. If in the two latter, allowance be made for stoppages caused by tin between valve and case, as not properly depending on the construction of the meter, there remain six per cent. of stoppages with Siemens meters, and none with Tylor.

Besides these stoppages, and the repairs rendered necessary by them, one hundred and thirty-five meters, or about

	Total Meters.	Total Stopped.	Per-centage.	Cause of Stoppage. Broken piston-ring	Gearing clogged.	Rust in Meter.	Tin betw'n Fan & Case
Kennedy	110	50	45	10=9%	40=36%	..	..
Frost	24	2	8	..	2=8%	..	..
Siemens	1,200	128	11	..	..	68=6%	60=5%
Tylor	310	16	5	..	..	..	16=5%
	1,644	196	..	10	42	68	76

eight per cent., required slight repairs, such as leakages in the stuffing-boxes, replacing dials, glasses, padlocks, &c., in which the meter rarely required to be changed. To complete the list it must be added that thirty were damaged by frost.

In respect of facility of repair and removal the Kennedy meter is the least handy from its size and weight. The others only need one workman to fix them, but the Kennedy and the largest size of the Frost meters require two. Tylor and Siemens meters are in this respect nearly equal, but the Tylor meters are somewhat cheaper to fix than those of Siemens, as no soldering is required.

The piston meters are so much more expensive than the others, that on this ground alone they are never likely to come into general use. For example, a $\frac{3}{4}$-inch piston meter by Kennedy cost about three times as much as a $\frac{3}{4}$-inch Siemens or Tylor meter, and a $\frac{1}{2}$-inch costs twice as much. This proportion should not form the basis of a comparison, as through meters of equal diameters, but of different systems, the maximum flow is not equal, the proportion of water passing through the $\frac{3}{4}$-inch and $\frac{1}{2}$-inch meters of Kennedy, Tylor, Siemens, being about 100: 65: 60.

With a pressure of 75 meters (246 feet) the maximum flow would be as follows:

System.	1 inch.	$\frac{3}{4}$ inch.	$\frac{1}{2}$ inch.
	Maximum flow in gallons per minute.		
Kennedy	70.2	37.2	22.0
Tylor	..	24.1	14.1
Siemens	48.2	23.0	1.31

These results are too small for Kennedy meters, for as the resistance in the pipes increases with the velocity, it is incorrect to take the calibre given by the manufacturer as the standard of comparison. Both with regard to cost and to calibre for pipes of a certain size, only meters of equal performance can be compared. Moreover, with a normal consumption, the gain in accuracy is not so great as to render a considerable addition to the cost advisable, for with thousands of meters any slight errors in some would probably be balanced in others.

As to the cost of maintenance, the above percentages cannot fairly be compared, as the meters of Kennedy and Siemens have had the most wear; but there can be little doubt that the cost of maintenance with the Kennedy meter is by far the greatest, and that Siemens meters do not seem to be so favorable as those of Tylor. As the latter is made of brass, stoppages caused by rust are not to be dreaded, whilst as the former consists almost entirely of iron, this cause of stoppage will continue until the iron be changed for brass. Rust brought in from the cast-iron street pipes is of no importance, as with well-tarred pipes the formation of rust is very slow. But even if any finely-divided rust does pass through, the best proof that it does not injure the meter is that none has ever yet been found in the Tylor meters. It is probable that the union of iron and brass under water favors the formation of rust in the Siemens meters.

With regard to damage by frost, in the Kennedy meters the cylinder always bursts; in those of Siemens part of the casing also gave way, and the indicator was pressed out of place; whilst in the Tylor meters no part had burst, the indicator only had been pressed out of place, and the soldering of the casing had come undone, so that the repairs to the latter cost less than those to the other two systems.

On comparing the results obtained from the four systems, the piston meters were not recommended for use in private houses, for, constructed as they are at present, the advantage of greater exactitude in measuring is more than counteracted by the increased cost of purchase and maintenance.

For house purposes the wheel meters of Siemens, or still better, those of Tylor, are more serviceable.

THE STRENGTH AND DIMENSIONS OF SPRINGS.

From "The Engineer."

The frequency with which we receive requests for information upon or reference to some work in which information may be found upon the strength, deflection, &c., of springs as used in railway carriages, wagons, and other vehicles, either as bearing or draw springs, is sufficient proof that that information is not easily to be found, and that no apology is needed for here reverting to the subject. Probably no piece of mechanism of universal use has received so little attention from writers of text-books on mechanical subjects as a carriage or wagon spring of the ordinary and most generally used form; yet it is an interesting and important subject, and a somewhat complex one taken in all its bearings, and one which has afforded a useful opportunity for the exercise of the talent of some of our mathematicians and physicists, but only a few of whom, however, have reduced the results of their labors to a form available for the use of engineers and constructors who desire properly to proportion the parts of springs they may be called upon to design for locomotives, carriages, road wagons, and other purposes. Not that sufficient information does not exist of a practical kind to enable those engaged in the design of springs to arrive at correctness in the proportion of their parts to suit given conditions, but that which does exist in a suitable form for the ready application of the practical engineer is scattered amongst the transactions or proceedings of learned and technical societies, or only to be found in the more expensive volumes not easily accessible to every one who may require the information. We propose, therefore, for the convenience of those of our readers who may require, but find such information difficult of access, to give here a short practical view of the subject, and, as far as our space will allow, to give such formulæ as are most generally applicable in the design of that kind of spring, namely, the plate spring, which practice proves to be the best for both bearing and draw springs. It is not our intention to dwell upon the curvature assumed by elastic bodies, nor upon the investigations upon which the formulæ we are about to quote are based, as this would be beyond the purposes of this article, and would unnecessarily complicate and lengthen it.

The value of a spring may be said to consist in its range of elastic flexure, and in its giving an uniform range of deflection under any one load between the minimum and maximum weight it is calculated to carry, and in its capability of overcoming the inertia of vertical motion of the load it is carrying within its assigned range of deflection; and, conversely, in its capability of permitting the vertical movement of the wheels and axle of the vehicle without immediately imparting that motion to the load, and thereby relieving the wheels and axle of the shock attending the work of suddenly overcoming the inertia of rest of the load, these properties coming into play respectively according as the load is suddenly checked in descent, when the wheels drop from a projection to the general surface of the roadway, or as the wheels are as suddenly raised by such a projection. In a vehicle not fitted with springs the whole weight of load and vehicle has to be raised through the height of every obstacle in its path on an irregular road, and if the vehicle be traveling at only four feet or five feet per second, the raising of the whole is effected so suddenly that the work of overcoming its inertia and lifting it, seriously tries the material of the wheels and axle, and adds very materially to the work of pulling the load. If, however, the vehicle be fitted with springs the work of suddenly lifting the whole load and vehicle is reduced to that of lifting the wheels and axle and deflecting the springs through a certain range, the latter being only equal to that of raising the weight necessary to produce such an increase of deflection. This work is absorbed by the springs, and is, in some cases, partially given out as useful work —as, for instance, when the obstruction is only momentary, as in passing over a fixed stone—in the descent of the wheels through the miniature gradient on the opposite side of the obstruction. This latter also obtains with the springless vehicle, as far as regards the descent of the weight and the slight forward impetus thus given to it, but the work of overcoming the inertia of the load is wholly lost.

Thus, with the springless vehicle the work added to that of traction in surmounting any obstacle may be taken as equal to that of overcoming the inertia of the load and lifting it, while, in the case of a vehicle fitted with springs, it is only equal to that of momentarily carrying an addition of load equal to that necessary to deflect the springs through the height to which, in the other case, the whole load has to be lifted. To meet these conditions, therefore, it is necessary that springs should, if possible, be uniformly flexible throughout their length, and should deflect through sensibly equal ranges for equal increments of load, so long as the load is within the limits of their capacity. Inasmuch, however, as the span of a spring slightly increases if normally curved, and decreases if normally straight, with every addition of load, the deflection becomes respectively more or less with each similar increment of load; no plate spring can, therefore, be equally efficient under greatly varying weights; hence it is of great importance, especially in railway vehicles, that the difference between the minimum and maximum loads should not be great, and that it should be accurately known and taken into consideration in the design of the springs.

The elastic strength of a spring is measurable by the load necessary to produce a given deflection within the limits of resilience of its integral parts; and on the other hand, its flexibility is measured by the range of deflection produced by a given load; while the strength of a spring is expressed by the load it will carry without approaching fracture or the limits of stability of its material. When a spring the plates of which are properly tempered is loaded beyond its elastic strength, it deflects through an abnormal range which generally indicates approaching rupture, or, if not actual rupture, such deformation as precludes its return to its original form, the strain on its material having exceeded its limit of elastic resistance; and this great increase of flexure must not be mistaken for increased elasticity. The absolute strength of a spring is thus not co-equal with its elastic strength, and the relations of the terms expressing the relative dimensions and properties as to strength and flexibility of plate springs may be thus summed up.

The absolute strength varies inversely as the span, directly as the number and breadth of the plates, and as the square of their thickness; while the flexibility varies as the cube of the span, inversely as the number and breadth of the plates, and inversely as the cube of their thickness. Thus the flexibility increases in a much higher ratio than that expressing reduction of strength with increase of span. These relations will be seen at a glance expressed in an algebraical form as follows, some of the formulæ being quoted from Mr. D. K. Clark's work on "Railway Machinery:"—

Let D=the deflection in sixteenths of an inch per ton load.

S=the span of the spring in inches when loaded.

b=the breadth of the spring plate in inches, considered uniform.

t=the thickness of plates in sixteenths of an inch.

n=the number of plates.

W=the working strength of spring in tons, or safe load.

Then

$$W=\frac{n\,b\,t^2}{11.3\,S}$$

$$D=\frac{1.66\,S^3}{n\,b\,t^3}$$

$n=\dfrac{11.3\,S\,W}{b\,t^2}$ and n necessary to a given elastic flexure, span, and size of plates=

$$n,=\frac{S^3\,1.66}{D\,b\,t^3}*$$

Plate springs, in almost all their applications, are liable to have their load suddenly applied, in which case the deflection will be, approximately, twice greater than when the load is gradually applied, or has been carried a short time, or sufficient time to allow of the spring adapting itself to the load after a series of oscillations. In other cases the load, or increment of load, is so suddenly applied as to become an impact force, in which case, supposing the spring to be without weight, and therefore without inertia, the deflection will be as if produced by a falling weight, and will be given by the formula

$$D=\sqrt{\frac{2\,w\,H}{\tau}+\left(\frac{w}{\tau}\right)^2}+\frac{w}{\tau};$$

in which D=deflection in feet, τ the static pressure in pounds which will produce a deflection of one foot, w the weight in pounds of the falling body, and H the height in feet through which it falls. In the case of bearing springs, H may be obtained by the formula, $H=\frac{v^2}{64}$, v being the velocity of impact force, or of the jerk which the spring has to resist, and, supposing for this purpose that the pressure required to produce one foot deflection is proportional to that required to produce deflection through small ranges—

$$\tau=\frac{n\,b\,t^3}{S^3}\times 259{,}000$$

This increase of deflection under sudden application of load must be borne in mind in arriving at a decision as to the range of deflection, and in designing the parts supporting and guiding the springs, and to prevent a spring getting away from its work by reason of its high velocity of recoil when the wheels suddenly drop from a higher to a lower elevation, it should be deflected through a considerable range by its permanent load, the amount of such deflection varying with the nature and use of the spring, and being for passenger carriages, goods, vans, &c., from $\frac{3}{4}$ inch to 1 inch.

The thickness of spring plates must be regulated by the span. A long spring may have thick plates, but a short spring with the same flexure must have thin plates, the thickness being so proportioned to the span and deflection that the extension and compression of the upper and lower surfaces of the plates are not sufficient to reach the limits of elasticity of the steel. Some years since thick plate springs were tried on the Great Western and other railways; but experience proved—what theory properly applied would have predicted—that thin plates were, for many reasons, superior, though we have heard it professionally stated within the past few months that it was not known why such was the case. Inasmuch as flexure cannot be obtained without extension or compression, or both, of the opposite sides of the plate bent, infinite flexure could only obtain with infinite thinness of plate; and as the possible elastic extension or compression of the material of which the plate is composed is limited to a small range, it is patent that there exists a quickly reached superior limit to the thickness of a plate of a given length which is to be deflected through a given range, and that if this limit is exceeded, deflection through the same range will be attended with permanent set or by fracture. Thus, with a given thickness and length of plate the range of elastic flexure is determined by the limit of elasticity of its material, and therefore the maximum economic thickness is similarly determined by the range of flexure and the limit of elasticity. The superior limit being thus found, the inferior limit will be determined by the assigned range of deflection, and by constructive limits as to number of plates or total depth of spring at center. It has been found by experience that for springs under $3\frac{1}{2}$ feet to four feet in span, the thickness of the plates should not exceed from $\frac{1}{4}$ inch in the smaller and

* The constants 1.66 and 11.3 were determined by Mr. Clark from the observed deflection and strength of springs of which he gives an account.

$\frac{5}{16}$ inch to $\frac{5}{8}$ inch in the larger spans while for springs above $3\frac{1}{2}$ feet and up to five feet and six feet span plates are now rarely used of more than $\frac{1}{2}$ inch in thickness with, in the larger spans, one or two $\frac{5}{8}$ inch top plates. Except for light carriages and similar vehicles the two, and in heavy vehicles and locomotives three, upper plates should be of nearly the same length, and the upper one of slightly increased thickness, the length of the lower plates decreasing by such steps that the spring may as nearly as possible deflect equally at every part throughout its length, except a few inches at the central fixed part or butt. The amount of deflection varies with the different applications of springs. In locomotive engines the flexure for the driving and trailing wheel springs ranges between $\frac{3}{4}$ inch and one inch and for the leading wheels not more than $\frac{1}{2}$ inch per ton of load, or even less, more especially when the springs are placed within the wheels. Passenger carriage springs varying in length from four feet to six feet, deflect from $1\frac{3}{4}$ inch to $2\frac{1}{2}$ inch per ton of load, while the common deflection of horse-box springs is from $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch per ton. For goods wagons a deflection per ton of load of from $\frac{3}{8}$ inch to $\frac{5}{8}$ inch is sufficient. Springs have been made with pieces of plate iron about $\frac{1}{8}$ inch thick placed between each spring plate at the butt, thus keeping the spring plate apart for some distance from the center. This, however, does not seem to be good practice; the paint on the surfaces thus exposed in the space between each plate is rubbed off during the working of the engine by the contact of the plates to a distance much nearer the center than when the engine is standing still or running at moderate speeds, and these interstices become seats of corrosion and wear. The plates cannot be "bedded" on each other too well, and paint is of little use between the rubbing surfaces; it is quickly rubbed off and out from between the plates, except at such inequalities as may exist whereat the plates do not quite touch, and here it may be of some service in keeping out water from such cavities; but the spring whose plates are best fitted together will last the longest.

ON THE CONSTRUCTION OF RAILWAY WAGONS, WITH SPECIAL REFERENCE TO ECONOMY IN DEAD WEIGHT.

By WALTER RALEIGH BROWNE, M.A., Assoc. Inst. C.E.

Minutes of the Proceedings of the Institution of Civil Engineers.

The present paper is mainly an essay towards determining the best and lightest form of goods wagon for general purposes to run on an ordinary English railway. It is, of course, a chief condition in such a wagon, that it shall enter readily into combination with the stock at present in use. The Author has therefore left unnoticed many points which it would be proper to discuss were the question that of designing the best type of vehicle for a new and independent system of railways. As an example, may be mentioned the various systems of central buffer and draw couplings which have lately come into extensive use on new foreign lines, especially those of a narrow guage. Whether these, in their own place, are beneficial or not, there can be no question that any vehicle intended for English main lines must have side buffers, placed at the same height from the rails, and the same distance apart, as those with which it will everywhere come in contact. For a like reason, while attention has been given to the practice of the best railways on the Continent and in America, this has only been considered as illustrating and throwing light upon the various characteristics of the English system. It was originally intended to include the subject of carriages as well as wagons; but this proved at once so large and so distinct, that, with the limits of time and space allowed, it was impossible to discuss it properly. Although alike in their principal parts, a carriage and a wagon differ widely in their essential conditions: not merely must a carriage be adapted to a much higher speed than a wagon, but considerations of smoothness, comfort, and luxury, wholly wanting in the latter, are of paramount importance in the former. Hence, although considerable information had been collected on the subject of carriages, it was thought better to reserve this for some future occasion.

The designing of a railway wagon has its peculiar difficulties, arising from the fact that, in addition to the ordinary strains, which can be calculated and allowed for, such a wagon is also subject to sudden and extraordinary strains which defy calculation. The violent shocks and strains of all kinds which a wagon is continually called on to endure need no description to any one who has ever watched the handling of goods traffic on railways. It is these which have chiefly to be considered in the building of a wagon. Extreme cases, such as a collision, or what Americans call a "derailment," cannot, of course, be guarded against; but the leading principle must be that all parts should be strong enough to sustain, without injury, the greatest shocks to which they are liable in ordinary working. It has not, therefore, been attempted to give a complete theoretical investigation of the strains on a wagon, or to frame a design and dimensions on theoretical principles. The dimensions found in the practice of the leading English railways have in general been assumed as substantially correct. What has been aimed at is to compare these with each other (checking them also by theory wherever possible), and thus endeavor to arrive at the lightest and most economical design consistent with the practical conditions of the case. These lead at once to the principle just stated, viz., that the strength of a railway vehicle must not, as in other structures, be proportioned to the load it has to carry. To show this by an example, take the ordinary sole-bar of an eight ton or a ten ton wagon. This, following the dimensions specified by most railway companies, will be a piece of American oak, twelve inches deep by five inches wide, and carrying a distributed load over a length of about fourteen feet. Taking ten tons as the load, and four tons as the weight of the wagon itself (exclusive of wheels, axles, and springs), this distributed load will be seven tons, or just one-half ton per foot. This load is supported on the two axles, which may be taken at eight feet apart. On calculating the bending moments at the center of this wheel base and over the axle respectively, it will be found that the latter is the greatest, and that its value in inch-tons is $\frac{3}{2} \times 18$, or 27. But calculating the breaking strain of a twelve-inch by five-inch section in the ordinary way, and assuming 4.7 as the modulus for inch-tons, the moment of rupture is found to be 564. This gives a factor of safety of twenty-one, or at least double what would be required in an ordinary timber structure. It follows that some other consideration must have led to the fixing of this scantling; and this of course lies in the fact, that the sole-bar has not merely to carry the load, but to carry it under all the varying circumstances of shock and strain which have already been alluded to.

It might seem an obvious deduction from the foregoing that the load of wagons (meaning thereby the total weight carried, in opposition to the 'tare,' or dead weight) ought to be largely increased. If the underframe of a wagon must in any case be made so strong that it would carry twenty tons as easily as ten tons, would it not be true policy to put something approaching to twenty tons upon it? This leads at once to the question, which ought obviously to form the first stage of inquiry, viz.: What is the proper load for an ordinary wagon?

Since, as already stated, the dimensions, and therefore the weight, of a wagon framework are, for the most part, fixed by considerations other than the weight it has to carry, the leading principle in this inquiry would seem to be that the load should be as great as possible. The way in which this principle has worked is shown by a glance at the history of railway rolling stock. The wagons first built carried only three or four tons, and weighed as much or more. From this the load was gradually increased to six tons, and then to eight tons and ten tons, at which it has stopped, although still the wagon is too strong for its load. Between these last two sizes the question may be said practically to lie. It is true there are still many six-ton wagons running, but few are now built, at any rate by railway companies themselves; in fact, the weight and cost of a six-ton is not much below that of a ten-ton wagon, while the load is little more than one-half. The question being thus narrowed, the difference between the weight and cost of an eight-ton and a ten-ton wagon has to be considered. It must be admitted that this is not great. An ordinary eight-ton wagon, as built by the Bridgwater Engineering Company, to run on the lines of the Great Western Railway Company, and to pass their inspection. The under, frame is entirely of oak, the sole-bars-headstocks, and middle bearers being all twelve inches by five inches, and the diagonals eleven inches by three inches. The wheels are three feet in diameter, with eight pairs of wrought iron spokes, and weldless iron or Bessemer steel tires, five inches by two inches, secured to the skeleton by rivets. The axles are five inches diameter within the boss, and 4½ inches diameter at the center, the journals are 7 inches by 3½ inches. The bearing springs are three feet three inches long by three inches wide, and consist of twelve plates each ⅜ inch thick, and one plate ½ inch thick. A similar wagon to carry ten tons differs from the above only in a few particulars. It is longer and deeper, the length being thirteen feet seven inches, and the depth three feet six inches. The underframe is the same, except as to the longitudinals. In the eight-ton these only run between the middle bearers, and are eleven inches by three inches: in the ten-ton they are one inch wider. In the end spaces the eight-ton has only two light pieces, 4 inches by 3½ inches, above and below the draw-bar; whereas the ten-ton has an eleven inch by three inch longitudinal running on either side the drawbar. It has also 1⅛-inch longitudinal tie-rods in place of ⅞-inch tie-rods in the eight-ton. The wheels are the same, but the axles are 5¼ inches inside the boss and 4½ inches at the center, the journals being 8 inches by 3¾ inches. The bearing springs are of the same length and design, but are four inches wide instead of three inches. The ironwork is the same throughout. The weight and cost of these extras are not great; in fact, while the tare of the eight-ton wagon is about four tons seven cwt. that of the ten-ton will not be above four tons fourteen cwt.; and, taking the price of the former at £60, that of the latter will not rule above £64. This comparison would appear to prove that the ten-ton wagon was decidedly the proper type, and that, as even here the factor of safety is far too high, a yet greater load might be resorted to. This conclusion, however, is negatived by the two following considerations:

(A) Wagons have not only to be hauled by locomotives; they have also to be shifted by horse power in yards and sidings: obviously, therefore, it is a fatal objection if a wagon is too heavy for a single horse to move it. Now it requires all the strength of a powerful horse to start a ten-ton wagon, fully loaded and in ordinary working order, upon a dead level: to start it on anything like an incline is too much for him: hence ten tons is, at any rate, the extreme limit admissible for the load.

(B) It is comparatively seldom that a wagon is loaded up to its full capacity. This arises from several causes. Thus (1) The contents of a wagon are often too bulky to make up the full weight. (2) The whole quantity of goods to be sent is often less than this weight: a truck comes into some private yard and is loaded, say, with three tons of castings, which are quite sufficient to constitute what is called a "truck-load": it is returned to the station, and thence goes direct to its destination, no weight being added, because nothing else offered having the same consignment. (3) The goods traffic on a railway is seldom equal in the two directions: hence wagons have constantly to be sent back empty. There are, unfortunately, no statistics with respect to English railways which will enable a judgment to be formed of the effect of these causes, and so to approximate to the average load of a wagon. For the railways of France, however, such statistics do exist, though not in a perfect form. These have been ably analyzed and discussed by M. Ernest Marche. Taking the six great railway systems of France, he finds that the ratio of the mean load to the capacity (or greatest load) of a wagon varies from 0.37 on the Chemin de Fer de l'Est to 0.444 on the Chemin de Fer du Nord: the average being exactly 0.4. On three of these railways the effect of the return of empty wagons can be separately estimated, as the number of these empties is registered: the percentage of these in the three cases was 25.35, 20.46, and 14.89 respectively. Eliminating this effect, the mean load of the wagons actually freighted can be ascertained: in these three railways its proportion to the capacity was 0.495, 0.472, and 0.473 respectively. The sum of his results amounts roughly to this: that on the railways of France one wagon in five is running empty and the other four are loaded to rather less than half their carrying capacity. For English lines, as already stated, no such data are available. It is possible that, from their much larger mineral traffic, they would show more favorable results: but the difference probably would not be great. Looking at these figures, and remembering that the extra weight and cost of a ten-ton wagon are entirely wasted whenever its load does not exceed eight tons, it would seem that the latter is probably the best figure to take for purposes of general traffic. An exception may arise in the case of coal or ore wagons owned by private firms and used only for a single purpose. These are commonly loaded at the pits to their full weight, and in such cases the shunting is so generally done by engine instead of by horse power that the other evil is not so important. Taking, however, an ordinary goods wagon, such as railway companies use for general purposes, the case may be summed up by saying that even if built for ten tons it will rarely have more than eight tons to carry, and that when it has, its cumbrons weight will be likely to cause trouble both at the beginning and at the end of its journey.

For these reasons in what follows eight tons will be taken as the standard capacity; and an investigation will be made of the best design for an eight-ton wagon, in all its parts. The conclusions arrived at will apply, with little variation, to a ten-ton wagon.

Before entering on this, however, there is one other point which it is necessary to discuss. This is the question, whether it is wise to provide as far as possible special types of wagon for the various classes of traffic. This proposal has often been made, and is certainly plausible at first sight. As it has been put to the Author, a heavy wagon may receive, say at High Wycombe, a consignment of cane-bottomed chairs, to be delivered at Bristol; and though built for ten tons, will be thus traveling with a load amounting only to a few hundred-weights. Or again, the Great Western railway forwards daily throughout the spring many trucks full of cauliflowers, grown in Cornwall, but destined for the London market. In these and all similar cases there is no doubt that special types of light wagons might be designed which would offer great advantages for the conveyance of these particular loads. But this course is open to two fatal objections.

(1) Suppose the light wagon to have deposited its freight of chairs at Bristol. It has then to be sent back, and it is of course desirable that it should not go empty. But the goods going from Bristol towards London are not of a light character, and perhaps the only consignment offering is a ponderous casting, or some heavy barrels of sugar. There is then only the choice between sending the wagon back light, or loading it beyond its proper capacity.

(2) Whether loaded or not, the light wagon will have to travel as one of a long train of wagons, most or perhaps all of which are of a much heavier and stronger build than itself. In cases of accident, or in the ordinary events of shunting, starting, and stopping, the light wagon will be much in the position of the earthenware pot in the fable: it will meet with so much rough usage, will be so mauled and hammered by its neighbors, that its life, under the most favorable circumstances, will be of short duration.

These two considerations seem fully to justify the course which has been taken by railway companies, both here and on the Continent, in reducing as far as possible the number of classes of wagons. There must always, however, remain a considerable number of varieties to provide for traffic to which ordinary wagons are unsuitable. The chief of these, as at present existing, are cattle wagons, timber wagons, coke wagons, platform wagons for heavy masses, such as boilers ; covered wagons for perishable goods, etc. But much may be done to economise even these : thus cattle wagons may be used for coke, or at another time for light bulky articles, such as would generally be carried in covered wagons ; boilers may be conveyed on timber wagons, and so forth. Far from agreeing with those who would wish to see classes of wagons multiplied, the Author's view is exactly the opposite. The end which should, in his opinion, be aimed at, is to have all ordinary wagons, not only on one railway, but throughout the kingdom, of precisely the same type and dimensions; this type being that which study and experience finally decide upon as the best. To help towards such a decision is, in fact, the principal object of the present Paper. Many advantages would result from this uniformity in wagons, which would of course extend to all their parts. A wagon, no matter what district it was built for, would always be free to work in any part of the country; whereas now it continually happens that a wagon is admitted without question by one railway company, which would be refused registration by another, as not complying with some special regulation. The wagons of the Taff Vale railway, for instance, are essentially different from those of all other companies, and would not be accepted by them: while a wagon that would be free over the whole vast system of the Great Western, would not be admitted on the Taff Vale. Again, any proposed improvement in design would of course have to go before a committee of wagon superintendents, and would thus at once be more easily brought to notice, and more thoroughly tested before approval. But the chief advantage would lie in the facility of repairs. All working parts being uniform, there would be no difficulty in keeping a stock at every repairing station, which would thus suit every wagon that could possibly arrive ; and the cost of effecting every sort of repair would be accurately known, and could be charged according to a fixed schedule. On this system railway companies might with great advantage undertake the whole repairs of wagons in their district, and thus do away with the present system of repairing contracts, with which they profess themselves dissatisfied. The matter would be as simple as possible. On a wagon being stopped at a station, the foreman in charge would notify to the owner the repair required, and proceed to execute it. There could be no question as to the charge, and the amount of this might be collected, if advisable, before the wagon was allowed to proceed on its journey. This would do away with all the objections now felt to freighters' wagons, as it would insure that they were kept up to the same standard of efficiency as those belonging to the railway companies themselves. This would be an advantage also to the freighters themselves, and they would also reap the benefit of getting all breakages repaired without an instant's delay; whereas a wagon is now frequently kept idle for days or weeks, while an axle-box or buffer-case of a special pattern is obtained from the only place, perhaps hundreds of miles distant, at which it can be manufactured.

Having, then, decided that the load of the standard wagon is to be eight tons, and that it is to be of a form as generally useful as possible, the next consideration is its design in detail.

For this purpose a wagon may be divided into the following parts, beginning from below :

A. Wheels and axles.
B. Axle-boxes.
C. Springs.
D. Underframe, axle-guards, &c.
E. Draw-gear.
F. Buffers,
G. Body.

A. *Wheels and Axles.*—The type of wheels and axles commonly employed for ordinary freighters' wagons in this country consists of a cast-iron nave or boss, wrought-iron spokes cast into it, and bent round to form a skeleton on which a steel or weldless-iron tire is shrunk and secured by rivets.

The diameter of the axle is five inches in the wheel seat, and $5\frac{1}{8}$ inches just inside the wheel, thus forming a shoulder; thence it tapers to $4\frac{1}{4}$ inches in the center; while outside the wheel it is reduced to $3\frac{1}{2}$ inches for the journal, which is seven inches long. These dimensions do not vary much from those in use on the chief systems both at home and abroad. Thus the Great Northern Railway Company specify five inches in the wheel seat, but reduce to four inches in the center, and $3\frac{1}{4}$ inches in the journal. The London and North-Western railway agree with these, but are content with $4\frac{3}{4}$ inches in the wheel seat. The Paris and Mediterranean give five inches in the wheel seat, $5\frac{3}{16}$ inches at the shoulder, $4\frac{1}{8}$ inches at the center, and $3\frac{5}{8}$ inches in the journal. The Cambrian railway and the chief German railways, however, are content with $4\frac{1}{2}$ inches for the diameter in the wheel seat; and the Grand Trunk of Canada specify $4\frac{1}{4}$ inches only, tapering to four inches in the middle.

The great diminution in size, both at the journal and in the centre, is, at first sight, hard to account for. The axle may of course be considered as a beam, loaded at each end (in the journals) by the half weight of the truck, and kept in equilibrium by the two upward pressures of the rails, passing through the wheels. It thus is under the action of two equal and opposite couples, in which the force is half the weight of the truck, and the arm is the distance between the centre of the journal and the centre of the boss. As the effect of such a couple is precisely the same at every point of the axle, it would seem that the diameter should also be the same everywhere. But it must be obvious that an axle is never endangered by the regular statical load brought upon it: its fracture is always occasioned by some sudden shock, such as might be caused by a stone placed on one of the rails, when the whole axle will act, for the moment, as a beam fixed at one end and receiving a blow at the other. This will of course produce its greatest effect at the fixed end, *i.e.*, in this case close to the undisturbed wheel; from thence the effect will diminish to its lowest value at the other, or disturbed wheel. This is the reason of the reduced diameter at the centre, the strain there being always less than at one or other of the wheels. The diminution is of course proportional to the moment of resistance, and therefore to the moment of inertia of the section: as this in a circle varies as the fourth power of the radius, the ratio of the diameter at the centre to that at wheel seat should equal $\sqrt[4]{\frac{1}{2}}$, or 0.84, a proportion very near to that found in practice.

The utility of this diminution has been questioned by M. Couche; but the above reasoning seems fully to demonstrate its theoretical soundness, while practically it effects a considerable saving in weight and cost.

The same reasoning, of course, accounts for the well-known fact that axles generally break just inside the wheel seat. This point is, in fact, that at which the cantilever is fixed (considering the axle as such), and therefore at which the intensity of strain is greatest. It is therefore desirable to avoid anything which may tend to weaken the section at this point. On some railways it is the practice to have a shoulder about $\frac{1}{8}$ inch deep on the axle, just inside the wheel, to prevent the latter from working inwards. The great tightness, with which wheels are now fastened to their axles, seems to render this unnecessary, and, in fact, on many lines it is dispensed with altogether. In any case, the difference between the first and the finishing cut of the lathe used in turning down the axle would seem to be amply sufficient. Anything more than this is objectionable, from the well-known fact that an abrupt change of section, in any piece subjected to impulsive strains, has a marked tendency to produce fracture. This, which has long been recognized and acted on in the case of shoulders, is probably also the reason why keys have frequently been condemned as means for fastening on wheels. But this would seem erroneous; for, in the case of a keyway, the shoulder runs parallel, and not at right angles to the direction of strain, and can therefore have no actual tendency to produce fracture. A keyway must of course be to some extent a source of weakness by diminishing the diameter; and to this is probably due the fact, observed by French engineers, that the fracture of an axle usually begins at the point diametrically opposite to the keyway. It is now becoming the practice to dispense with keys altogether, and simply to use so powerful a pressure in forcing the wheel on to its axle, that the adhesion so produced is sufficient to keep the wheel tight under all possible strains. It may, however, be questioned whether this is not itself dangerous in another way. The wheel being thus, as it were, incorporated with the axle, the latter is somewhat in the position of a piece whose section alters suddenly and to a large extent. The evil of this is well known, and has been already alluded to. At the same time the boss is put into a state of violent strain (at least in its inner portion), and it is thus liable to split when any shock comes upon it. The splitting of bosses is, in fact, of frequent occurrence.

Looking at these considerations, there seems great want of a method for uniting these wheels and axles which should be sufficiently firm, without throwing either into a state of internal strain. An obvious method would be to make the wheel seat oval or hexagonal, instead of round; but this would, no doubt, add to the expense of machining. Perhaps the single key as now used, with some simple arrangement to prevent the possibility of its working loose, is as good a system as exists at present; at any rate, until some better be devised, four and a half inches at the wheel seat, tapering to four inches in the middle, would seem to be the smallest diameter permissible for an axle.

The greatly diminished size which may be given to the journal is due to the fact previously noticed, viz., that it is a blow delivered by one rail which produces the most violent strain on an axle. Another cause, however, no doubt comes in to assist the journal, and that is the operation of the bearing spring, through which the weight is transmitted. When a wheel passes over an inequality, the weight of the truck must of course come heavily down upon the journal; but the effect is taken off by the yielding of the bearing spring, and changed from a violent blow into a graduul pressure. This leads to the inquiry whether the shock to the wheel seat might not be, to some extent, "cushioned" in a similar manner. This clearly implies the giving of a certain amount of elasticity to the wheel itself; and this has apparently been accomplished in the wooden wheel system, now so frequently used, especially for carriages. The space between the boss and the tire is here filled up by a series of hardwood blocks, set endwise to the fibers, and secured both at the boss and the tire by rings of plate iron. This system has been in use on the London and South-Western railway for thirty years. The wood used in the first wheels was teak, which was saturated with oil and white-lead by a process similar to creosoting, *i.e.*, by placing the blocks in a receiver, first exhausting the air to remove the sap, and then forcing in the oil and lead under a pressure of ninety pounds to the square inch. Some of these wheels have lately been taken off and cut down to a smaller diameter; and the Author is assured by Mr. W. G. Beattie that the wood was perfectly sound. He was at the same time informed that the breaking of an axle had never been known to take place with these wooden wheels—a result which can only be due to the elasticity they possess. These wheels are lighter than ordinary iron wheels, the total difference being as much as 3 cwt. per pair; and their first cost is not much greater. The tires rest directly on the wood, so that no skeleton is required, and are of course secured by some kind of clip fastening, and not by rivets. This is not the time to discuss the vexed question of riveted tires; but it cannot, of course, be denied that a rivet-hole must make a weak place in any piece, especially one so heavily strained as a tire; and now that other fastenings can be provided at little extra cost, it may be doubted whether the time has not come for giving up the old system altogether.

In the sharpest possible contrast to the elastic wooden wheel is the chilled cast iron wheel so much in vogue in America. The merits of this have been more than once discussed in this place, and also the question of its manufacture in England. It is believed that there would be no real difficulty as to the manufacture, provided pig iron of the requisite purity were used. This would now have to be obtained from Sweden, Russia, or elsewhere; but should a demand arise, charcoal blast-furnaces (of which one still exists at Lorne in Argyleshire) would probably soon spring into being. The excessive rigidity of this wheel would certainly seem to form an objection to it; though this would appear not to have been felt in the States, where the permanent way is often of the roughest description. Possibly the curve which is usually given to the section between the boss and tire, in order to allow for contraction, may give to the wheel, when in use, a certain degree of elasticity.

Before leaving the subject of wheels and axles, it should be noted that one important point to be aimed at is the prevention of the wear of the journals. The skeleton and boss of a wheel, and the whole length of the axle, are practically subject to no wear and tear whatever; and though tires wear out, they can easily be renewed. Thus the life of a pair of wheels would be indefinite were it not that the journals wear down, and the wheels are then useless. An obvious remedy is to "bush" them with brass or white metal; but as obvious an objection is, that the arm at which the bearing friction acts would thereby be increased. Another device would be to make the journals in separate pieces and screw them into the ends of the axles; but there might then be fear of their working loose. This point is one which would seem worthy of attention.

B. *Axle-boxes and Axle-guards.*—The next part of the wagon to be considered is the axle-boxes, involving the important question, whether oil or grease should be preferred as a lubricant. At present oil is universal in hot climates, is general in Germany and in the United States, and is largely used in England by railway companies; but grease is, in this country, almost the only lubricant used for private wagons. The advantages of the latter are its cheapness and facility of application. The real ground of its use is probably the much greater cost of an oil axle-box: thus Beattie's and Beuther's axle-boxes each cost about £5 per set, exclusive of royalty; while ordinary grease axle-boxes weigh less than 3 cwt. per set, and cost little over £3. The advantages claimed for the oil axle-box would seem to outweigh this difference in prime cost. These are: (*a*) The quantity of the lubricant used is so much smaller that it needs to be renewed very seldom. (*b*) Should the supply run short, the box heats, not suddenly, like a grease box, but gradually, taking two or three days to arrive at a dangerous temperature: this of course enormously increases the chance of its being discovered in time. (*c*) There seems no doubt that the friction resistance is decidedly smaller with oil than with grease, a point of vital importance. A comparison made some years back, between the vehicles of the Orleans railway, using oil, and those of the Lyons railway, using grease, did not prove any marked difference between the two; but in a comparison of this kind the result may be affected by so many other conditions that it must always be regarded with suspicion. On the other hand, the experiments of M. Vuillemin and others showed a great superiority on the side of oil; and these have been confirmed by experiments on the London and South-Western railway. The general result of these was that with oil the resistance to traction of a wagon in motion was only three pounds per ton, while with grease it was about nine pounds. On the other hand, the resistance of a wagon at rest to being started was somewhat greater with oil than grease, but the difference was not large (fifteen pounds and thirteen pounds per ton respectively). Should railway companies, as previously suggested, take in hand the repairs of all wagons running on their system, they would probably provide for the greasing as well, charging a moderate sum per annum, which owners (to whom greasing and hot boxes are a perpetual source of trouble) would in general be most willing to pay. It would then probably be much to their advantage to forbid the further manufacture of grease axle-boxes altogether, and settle upon some definite system of oil lubrication.

With regard to axle-guards, the W-shape, now universal, probably admits of no improvement. The thickness of the iron, $\frac{3}{4}$ inch, is also fixed by general consent. Its width, however, is generally, in the Author's opinion, excessive: on many railways $3\frac{1}{2}$ inches is still the minimum. It is believed that (where the iron is, as it ought to be, first-rate) a width of $2\frac{1}{2}$ inches is ample, even for the crowns, and that for the wings $2\frac{1}{4}$ inches is sufficient. It must be remembered that both the pulling and the buffing strains are transmitted through the body of the wagon; consequently the stress thrown on the guards by sudden stopping or starting is only that due to the momentum of the wheels and axle, weighing together about fourteen cwt. This can never be very great; and, even with the moderate widths now used by some railways, the fracture of an axle-guard is almost unknown.

C. *Springs.*—It is remarkable that conical bearing springs are general in America, but are unknown in this country. A comparison between these and the common laminated springs would be interesting, but it has not been possible to obtain the requisite data for making it. The spring of the Highland railway is flat and long, like a carriage spring, consisting of nine plates $3\frac{1}{2}$ inches by half inch; the uppermost three feet six inches in length. On other lines the plates have a decided camber; their width varies from four inches on the Caledonian to three inches on the Great Western, and whilst in the former case they are ten in number, each half inch thick, in the latter there are two plates $\frac{5}{8}$ inch, and fourteen plates $\frac{5}{16}$ inch. A much lighter spring is that used on the Cambrian railway, which consists of ten plates 3 inches by $\frac{3}{8}$ inch, and one plate 3 inches by $\frac{1}{2}$ inch. Probably a simpler form even than this would suffice. In a wagon great flexibility is not necessary; and strength is best consulted by making the plates few and thick; since in a laminated body the several parts act almost independently, and the sum of their strengths gives the real strength of the whole. Hence, as the strength of a beam varies as the square of its depth, six plates $\frac{1}{2}$ inch thick will more than equal ten plates $\frac{3}{8}$ inch thick; and it would seem that a spring consisting of only seven plates 3 inches by $\frac{1}{2}$ inch would have sufficient strength, and probably also sufficient elasticity. Such springs would not weigh above 2 cwt. 2 qrs. per set, in comparison with 4 cwt. 2 qrs. 20 lbs., the weight of Great Western springs.

D. *Underframe.*—An ordinary oak underframe for an eight-ton wagon. It may be worth remarking that the diagonals of the under-frame should always incline from the centre towards the buffers, and not, as sometimes seen, from the ends of the middle bearers towards the drawbar. In the latter case they give no assistance against the pull of the draw-gear, because they cannot act as ties; in the former they are able to assume their proper function as struts, and thus help to support the "buffing" strains.

This difficulty as to ties constitutes, in fact, the chief disadvantage in wooden structures. In an under-frame it compels the use of wrought iron tie-rods both along and across the frame. Looking at this, an under-frame of combined wood and iron would seem desirable, in which angle or T-irons should act both as supports and ties; but such combinations are rarely successful. Carrying the same idea still further, many engineers have built under-frames wholly of iron, but the advantage of this is more than doubtful. For on comparing the properties of American oak and wrought iron, as given in Rankine's Rules and Tables, p. 195, it will be found that the following is approximately true: a bar of iron in comparison with an exactly similar bar of oak has five times the strength to resist tearing, six times the strength to resist crushing, and four times the strength to resist cross-breaking; but, on the other hand, it has ten times the weight, and twelve times the value. Hence to have, say, a sole-bar in iron of the same strength as one in oak, one-sixth the scantling must be given; but in that case it would weigh 66 per cent., and cost 100 per cent. more than its rival. This result is completely borne out in practice. The weight of the oak underframe shown in the diagram is about 12 cwt. (including tie-rods, etc.); and its cost at present rates is about £7 12*s.* But an iron under-frame of the same general character and size, if made with the usual dimensions, would weigh about 16 cwt., and cost about £15 13*s.* Against so large a difference, there seems only one point to urge in favor of iron, and that is its greater durability. But this may easily be bought too dear. In the first place wagons get out of date. This was the case with the early railway wagons, which were soon superseded; and at the present moment a striking instance is afforded in the broad-gauge stock of the Great Western railway, which was built in the most durable style, but is now being in a great measure abandoned, or converted, at a heavy cost, to narrow-gauge. But apart from this, the ordinary life of a wagon is so hazardous, exposed to so many natural and unnatural shocks, that its average duration is much below what would be due to the ordinary processes of decay. On this point, as might be expected, opinions differ much, and statistics are hard to obtain. The engineer of one important railway stated that the number of wagons destroyed by accident was so small as not to be worth consideration. The engineer of another line, equally important, held that on an average wagons did not run above twelve years before coming to a violent end. Probably the truth lies between the two. At any rate there seems good reason to conclude that durability is by no means the most important point in the designing of such a structure as a railway wagon; and, in fact, so fully has this been realized by some leading authorities, that on the vast system of the Midland railway, for example, iron underframes are completely unknown.

Another point remains for consideration, viz., the scantling to be given to the headstocks, sole-bars and middle bearers. They are all twelve inches by five inches, and this is the scantling fixed by most of the leading railway companies for private wagons. At the same time dimensions much below these are not unknown. There are six-ton wagons now running on the Swansea Vale railway whose sole-bars, &c., are only $9\frac{1}{2}$ inches by $4\frac{1}{2}$ inches. The Highland railway are content with 11 inches by $4\frac{1}{2}$ inches, and the Caledonian railway with $10\frac{1}{2}$ by $4\frac{1}{2}$ inches. And it is specially to be remarked that those companies who insist most strongly upon the full dimensions in private wagons are yet often found to fall short of them in those they build for themselves. It was, in fact, admitted by a high authority that the full dimensions were not really necessary, but were retained to provide against the possible use by private builders of inferior materials. Even if requisite for the sole-bars and headstocks (on which the chief strains are brought), these dimensions would seem needless for the middle bearers. The reason for strengthening these was, no doubt, the fact that with ordinary draw-gear the whole strain of traction is brought upon them; but with continuous draw-gear this is not the case, and then these middle bearers (especially if the bottom planks run across, not along the frame) have but little to do. In any case, the model wagon may be assumed to have sole-bars and headstocks of 11 inches by $4\frac{1}{2}$ inches scantling, and middle bearers and diagonals of eleven inches by three inches.

E. *Draw-gear.*—The draw-gear universally employed for wagons consists of a hook at each end of the truck, with a shackle and chain attached to it. This hook is welded on to the end of a bar ($1\frac{3}{4}$ inches round in general), which passes through the headstock and generally also through the middle bearer, and is made to bear against the latter by means of a nut and indiarubber washers. An improvement on this is the continuous draw-gear, which consists in uniting together the inner ends of the two drawbars so that they form one system, and the traction is obtained by the draw-hook in rear of the truck bearing against its headstock. It is clear that in the first case the body of the truck forms itself a link in the chain of traction, and the whole resistance of the hinder part of the train is transmitted through it as a tensile strain. In the continuous system, on the other hand, the drawbars form the chain, independently of the wagons, and the whole strain on any one of the latter is that due to its own resistance to traction, conveyed in the form of pressure which it is best adapted to resist. The disadvantage of the continuous system is its great weight and expense. The heavy drawbars, extending the whole length of the truck, do not add to its strength in the slightest degree, and the 'cradle,' or intermediate piece which connects the drawbars together is always cumbersome and costly. In view of this a system of continuous draw-gear has been designed. The indiarubbers are contained in a wrought-iron case fixed upon the outside of the headstock: and the strain is transmitted through four $\frac{7}{8}$ inch rods, which at the same time act as the longitudinal ties of the underframe. The draw-hook terminates in a short shank which passes through the headstock to get an inside bearing. The advantages aimed at are: (1) A saving in weight and cost, since the ordinary tie-rods are dispensed with. (2) The avoidance of a weld in the drawbar, hence the risk which always attends a welded piece is absent. (3) The indiarubbers are outside the truck, and more easily accessible when required. (4) The strain is transmitted through four rods instead of one; and should one of these happen to be of inferior quality and give way, the other three would probably hold, at any rate till the wagon reached some place where the failure would be observed.

Before leaving the subject of drawbars a word may be said upon safety chains. These, which were once in general use, have been mostly abandoned, for it has been found that if a drawbar breaks, the safety chains inevitably also break under the shock brought on them by the separating train. This, in fact, has so often been the case that their discontinuance is not to be wondered at; indeed, in more than one instance they have done actual harm by one of them holding while the other gave way, and thus getting the wagon across the line.

F. *Buffers.*—There would seem to be a growing inclination to abandon spring buffers—at least in mineral wagons: and this tendency, once begun, is likely to increase, since a wagon with spring buffers placed in a train of others having "dead" buffers only is sure to fare badly. In the more expensive class of wagons, such as are built by railway companies, the wrought iron buffer seems to be superseding the cast-iron.

The Midland railway and also the Great Western now build their wagons with a buffer system similar to that used for carriages. The buffer-heads are attached to long rods, which bear against the two ends of a large laminated spring laid horizontally across the underframe outside the middle bearer. The drawbar is widened out and a slot made in it, through which this spring passes, so that it acts against the traction as well as against the buffing strains.

G. *Body.*—The outside dimensions of the body are left in general to the judgment of the builder. The Taff Vale railway, however, specify that the capacity shall be between 240 and 245 cubic feet, and that the wheel base shall not be more than five feet six inches. This necessitates an exceedingly short and deep wagon. On other lines the wheel base is generally specified to be about eight feet, and the length, especially in the North of England, is at least thirteen feet, and often fourteen feet or upwards. The Author considers the Taff Vale type, though perhaps exaggerated, represents much more nearly what should be aimed at. The advantages of short wagons are manifold. In the first place, they effect a considerable saving in weight and cost. The sheeting is of course nearly the same in any case if the cubic contents are the same; but the sole-bars, side rails, and diagonals are shortened, and so are the drawbars, capping irons, and longitudinal tie-rods. Secondly, short trucks are handier in themselves, and require smaller turntables. Thirdly, they make up into shorter and handier trains. This is of great importance when the enormous length of goods trains at the present day is considered, and also that such a train has usually to move its whole length twice (first past the points and then over them) in order to get into a siding. Fourthly, a short truck cannot fail, as a long truck often does, by the 'hogging' of the sole-bars. Supposing a sole-bar to be uniformly loaded, and supported on axles eight feet apart, it may be shown that it should not overhang more than two feet ten inches at each end if the strain over the bearings is not to be greater than that at the center; but, considering the weight of the head-stock, buffers, and sheeting, &c., which are placed at the extreme end of the sole-bar, it would seem that two feet three inches is a more fitting limit. This would give a length of twelve feet six inches; and it is thought that this, with a width of about seven feet six inches, and a depth of about two feet nine inches, forms the most suitable body for an eight-ton wagon. If there are no end doors the two end planks may be curved with a rise of five inches, and then the depth at the sides need not exceed two feet six inches.

The thickness of the planking has also to be considered. In general that of the bottom is two and a-half inches, and that of the sides either two and a-half inches or three inches. The top edge is protected by a capping iron or flat bar. This bar is simply screwed down to the top plank, and does not add to the strength of the wagon in any way. It would appear feasible to transform this into a light angle-iron (say $2 \times 2 \times \frac{1}{4}$ inches) which should be bolted at each end to the corner plates (being let into the top plank throughout its length) and also to the inside knees wherever they occur.

There would thus be formed a sort of light wrought iron frame for the body, which would materially strengthen it, and the thickness of planking might then be reduced to two inches, or even less. The Caledonian railway even now employ planking only one and a-half inch thick, strengthened by stanchions and a top rail, it is true; but this seems sufficient to prove that the thinner planking would not suffer unduly from wear and tear.

The inquiry is now concluded. For an eight-ton goods wagon, embodying the dimensions, &c., arrived at for the several parts, the tare weight would be about three tons eighteen cwt. while the eight ton wagons now running weigh from four tons eight cwt. to five tons ten cwt.

Even so the proportion of tare to load (or of dead weight to paying weight) seems to be high; but the reasons stated at the commencement preclude the hope of the reduction being carried much further. It remains for the Author to express his obligations to several gentlemen connected with railways, both for valuable information and for drawings of wagons, many of which are exhibited: especially to Mr. Armstrong, of the Great Western Railway; Mr. Beattie, of the London and South-Western railway; Mr. Clayton, of the Midland railway; and Mr. Herbert Wallis, of the Grand Trunk railway of Canada. His aim throughout has been to raise points for discussion rather than to lay down authoritative rules, and with this understanding he now leaves the matter in the hands of the Institution.

RIVERS POLLUTION.

By JAMES P. KIRKWOOD, C. E.

Abstract of the Report to the State Board of Health of Massachusetts.

Part I.—Preliminary.

The law requiring the special information, and, incidentally, the examinations to be noticed in this Report, reads as follows :—

An Act to provide for an investigation of the question of the use of Running Streams as Common Sewers in its relation to the Public Health.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows :—

Sect. 1. The State Board of Health shall investigate, by themselves or by agents employed by them, the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth, especially with regard to the pollution of rivers, estuaries and ponds by such drainage or sewerage; and to devise and report a system or method by which said cities or towns may be properly drained, and said rivers, estuaries and ponds may be protected against pollution, so far as possible, with the view of the preservation of the health of the inhabitants of this Commonwealth, and the securing to the several cities and towns thereof a proper system of drainage and sewerage without injury to the rights and health of others; also, to report how far said sewage may be utilized and disposed of.

Sect. 2. Said State Board of Health, or agents employed by them, may enter upon and make surveys of lands, so far as may be required, and without unnecessary injury thereto, and said Board may employ such assistants, with the consent of the governor, as from time to time may be expedient. They shall report to the next general court, not later than the first day of February, eighteen hundred and seventy-six.

Sect. 3. The compensation of the members of said State Board of Health, or agents employed by them, for services under this Act, shall be fixed by the governor and council, which, with the expenses incurred by them, to be approved by the same authority, shall be paid by the treasurer of the Commonwealth, on the warrant of the governor.

Sect. 4. This Act shall take effect upon its passage.

The above Order has in view two important means towards the security and improvement of the general health, one of which, sewerage or drainage, has long been pretty well understood, and to some extent acted upon; and the other, the maintenance of the purity of our running streams, has been in the United States as generally neglected.

Throwing together the sentences of the law which refers to sewerage, it requires the Board of Health "to investigate the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth," and to devise and report "how far said sewage may be utilized and disposed of."

In regard to the rivers of the Commonwealth, it requires the above investigation to be made "especially with regard to the pollution of rivers, estuaries and ponds by such drainage or sewerage," and to devise a system by which "said rivers, estuaries and ponds may be protected against pollution, so far as possible, all with the view of the preservation of the health of the inhabitants of this Commonwealth, and the securing to the several cities and towns thereof a proper system of drainage and sewerage, without injury to the rights and health of others."

In previous reports of this Board, particularly the fourth and fifth annual reports, the general questions of sewerage of towns and pollution of rivers have been very thoroughly discussed. In reviewing the same questions now, some repetition will be unavoidable; but, remembering what has been already said, and that the literature of the subject is now large and accessible, we will endeavor to condense what may require to be said again to meet the Act already quoted, and to further the objects which it has in view.

Without attempting to keep the subjects above defined separate, where they may naturally come together, the present condition of our rivers will first be looked at—how far they are polluted now, and the evils which that pollution entails, whether under ordinary or exceptional circumstances. To this end, as examples of the polluting exposure to which the rivers of the State are subject now, an exposure against which there is practically no defence through the common law, five of the river-valleys of the State have been examined, and an account taken in each case of all the points where sewage or pollutions of any kind enter the river, including necessarily all factories, the refuse fluids of which enter, and to that extent degrade, the waters of the several valleys. The fluid waters flowing from factories of all kinds will be seen to be the chief cause of pollution in the valleys examined, except the Blackstone; the animal sewage, being as yet but rarely concentrated, is not so palpable, but it is greater, probably, in the aggregate than can be made to appear in the statistics.

The sketches of the valleys attached to this Report will show to the eye their extent and general character, with the positions of the objectionable elements referred to. The statistics will be summarized presently; but, although the mere statement of some of them will sufficiently offend the cleanly instincts of most persons, there are others who will reasonably want to know whether the delivery of a certain amount of such polluting fluids or matters into a river-course necessarily renders that water unfit for domestic use, and injurious to health. The facts affecting this view of the case, to whichever side they lean, should be fairly presented.

It may suffice to refer to the Thames and the Lea, at London, as exhibiting both the apparent insensibility of the human stomach to waters exposed to a considerable measure of impurities, as well as its fearful sensitiveness under the use of the same waters (polluted, some would say, but lightly by sewage) during the prevalence of an epidemic.

It cannot be said that all rivers receiving sewage in any degree are unfit for use; for, of the rivers from which water is freely drawn for human use, there are very few that are not exposed to pollutions of one kind and another, even up to their sources. There is no such thing as pure water, even at the sources, nor anywhere except in a laboratory. Pure water, therefore, or good water, in ordinary parlance, is understood by the engineer to mean a palatable, wholesome water, not insipid like rain-water, and not open to the reception of that class of impurities which endanger the individual health. Palatable water will always have some foreign ingredient in it, which is not necessarily unwholesome; when pollution, therefore, is spoken of in connection with rivers, it refers to those kinds of impurities which, when known, should make the water repulsive for human use. That it does not always do so is the effect of custom, which gets men habituated to almost any evil which is ever present, especially when it cannot by an effort of will be promptly remedied. In this case, too, the evil is but rarely present to the senses at the point where the water is used; it is only known by common report.

The Second English Rivers Pollution Commission give the following as "the chief characteristics of unpolluted water: It is tasteless and inodorous, possesses a neutral or faintly alkaline reaction, rarely contains in 100,000 pounds more than one-half pound of carbon and one-tenth pound of nitrogen in the form of organic matter, and is incapable of putrefaction, even when kept for some time in close vessels at a summer temperature."

In our own country, we have the water-supply of Philadelphia to point to, taken from the Delaware and the Schuylkill, both at places where the water has been much exposed to pollution; and we have the water-supply of Cincinnati, taken from the Ohio River at a point very near to the largest and worst sewer of the city. In Philadelphia, at least, the effective pollution is probably greater than on the Thames, because the water is taken from the streams at points nearer to the polluting deliveries than on the Thames; though these deliveries may be much less in volume when compared with the general volumes of the streams which receive them.

On the Schuylkill, the aggregate of polluting fluids entering the river above Philadelphia is represented to be greater than on the Thames above London, comparing equal volumes of their waters.

We are presented with the same anomaly here that occurs when we compare the annual death-rate of London, under the exposed waters of the Thames and Lea, with the death-rates of other cities that are supplied with water purer in every way.

The latest statistics within our reach give the annual rate of mortality for New York as twenty-nine per thousand of the population, taking the average of the four years 1870, '71, '72, '73. The average of the same four years for Philadelphia gives twenty-three per thousand. But the Croton waters which supply New York are not exposed, except in a very small way, to any of the impurities which so markedly mix with the waters of the Schuylkill and the Delaware.

The populations of these two cities are somewhat different in general character. New York includes more of a foreign and a floating population, and is in some of the wards very densely occupied. A large part of its working population leave the city at night, however, and find cheap homes in New Jersey and Long Island, whereas the working population of Philadelphia remain within the city lines.*

The reports of the Board of Health of New York give the following as the annual death-rates per thousand, for 1871 and 1872 in the British cities named. I am not able yet to give the returns for 1873 and 1874:

* By the census of 1870, we have the following statistics:

Cities.	Total Population.	Per cent. of Foreign Population.	Total area of city in square miles.	Average population to each square mile.	No. of dwellings.	No. of persons to each dwelling.
New York....	942,292	.44	40.6	23,209	64,944	14.72
Philadelphia..	674,024	.27	122.0	5,525	112,266	6.01

The average density of population is considerably less in New York than in London, which has an area of 117 square miles, and had by the last census (1871) a population of 27,793 to the square mile. The average density of population in Liverpool is even twice as great as it is in London. Philadelphia has lately annexed a large area of country which is very sparsely settled.

	1871.	1872.
Liverpool	35.1	27.1
Leicester	26.8	26.8
Manchester	28.6	31.2
Edinburgh	26.9	26.5
Glasgow	32.9	28.4
Dublin	26.2	28.9

All of these English cities derive their water from grounds which are free from the polluting influences to which the River Thames is exposed, and yet the death rate of London is somewhat below that of any of these cities, being 24.7 for 1871, and 21.4 for 1872. This kind of comparison is necessarily imperfect, because in the manufacturing cities the population is more concentrated than in London, and the amount of deprivation and exposure leading to sickness and suffering probably much greater. The sewerage, too, of most of these places is still imperfect as compared with London. Still, under ordinary circumstances, it would seem to be plain that a considerable measure of impurity may flow into river-waters without sensibly affecting the health of the communities living on them and using them, under ordinary circumstances, provided that the water is drawn from points five to ten miles distant from where the poison enters the stream. The London water companies take their waters from the river at Hampton and Kingston; the sewages of Windsor and Eton enter the river some fifteen miles or more above these points; and, although the banks of the stream, particularly in the eddies, are said to show marks of the impurities which it has received above, its presence at Hampton, where the water is taken for the city, cannot be sensibly distinguished, or proven to have communicated to the water any dangerous qualities, under ordinary circumstances. For this condition of things (as now understood), we are indebted to the fact of the volume of sewage being very small compared with the volume of water in the river; the sewage must be so largely diluted as to have become almost an inappreciable quantity. To secure this dilution, it is obvious that, if the river be a quiet, slow-flowing stream, it might take ten to twenty miles to produce the required mixing; but if fast-running, or pouring over dams and falls of water, a much less distance would have the same effect. If we dilute urine with a sufficient quantity of clean water and mix it thoroughly, no chemist could detect the impurity; nor could it be shown to be dangerous in any sense, however disgusting the knowledge would be that it was there.

A larger measure than this, including trade impurities, probably exists in the Thames water now at the points where it is used; for at this date (1875) we are informed that Oxford, Reading, Abingdon and Windsor still pass their sewage into the river, although they have commenced sewage works which will in time more or less remedy the evil.

It was long thought that sewage was destroyed by running water, but now it is believed by chemists to be all but indestructible there, and to be rendered insensible, as already said, and inert, only by being mixed largely,—thoroughly diluted, in other words, with at least one hundred times its volume of good water. Sewage distributed over land is appropriated like manure by the vegetation which it finds there, but, passed into running water, it finds little or nothing there requiring its aid. In the one case, it is where it is needed; in the other case, where no profitable use can be made of it. In the still, clear water of shallow ponds, vegetation will often be profuse, protecting the water by such large floating leaves as those of the pond-lily from the hot rays of the summer sun; and in the clear pools of sluggish but pure streams, the vegetation along the banks will often be considerable; but in running water there is but little vegetation,—none, it may be said, if the water is turbid or foul. In running water, therefore, such as mostly prevails in the rivers of the State, the sewage flows on with but little absorption from the very few plants it meets.

It is not to be forgotten that the Thames water is very sensibly improved by the process of filtration to which it is subjected before being delivered to the city. This filtration does not merely remove the sediment which may be in suspension, but it removes a large portion of the organic matter (forty-seven per cent., Dr. Frankland says) which finds place in the natural waters of the river. In the comparison made above with other cities, it is to be noted that the waters of Manchester and Glasgow are not filtered; the waters, however, of Leicester, Liverpool, and Dublin are filtered, and a portion of the Edinburgh supply.

In large cities, any measure of uncleanness and impurity will be submitted to by the poor and helpless; and until those who are better off are roused in their own interest, and for their own protection, to remedy this tendency, the foul taints engendered by the indifference to cleanliness which accompanies extreme poverty, as well as the inaction which belongs to it, will contaminate and render supine the rich; and, as in many European cities, both classes will have under their noses, it might also be said, a condition of things that could never be tolerated here.

If we look again to the Thames, the lessons from which are very marked, we are reminded that the very impure water delivered to the city before 1849 was borne with until the cholera appeared, and the fearful exaggeration of its ravages within the city was traced prominently, if it cannot be said entirely, to the character of the water used. How much mischief is done by the measure of sewage impurities which is drunk now with the waters of the London supply and the Philadelphia and Cincinnati supplies, cannot be known, so slow and insidious may be its effects on the constitution while no epidemic is present to bring the poison into daylight.

To understand fully the risk which follows the contamination by sewage, especially of potable waters, it will be necessary to review the cholera epidemics of 1849 and 1854 in London.

We are not able to make the kind of comparison that would enable us to understand the benefit to the health of a city population consequent on the use of entirely unpolluted water, as contrasted with the effect produced by the use of polluted water on the health of another population similarly situated. Such cases, in all respects similar, do not exist; but, from the water-history of London, the effect of using different measures or degrees of polluted water can clearly be traced. The cholera epidemics of 1849, 1854 and 1866 give very distinct lessons in this respect, and their histories, so far as they are connected with the water-supply, will therefore be briefly traced.

The metropolis of London is supplied with water by eight companies, five of which take their water from the Thames, two from the river Lea, a tributary of the Thames, and one (the Kent) from artesian wells in the chalk.

During the cholera epidemic of 1848–9, all the companies delivered their water to the city without filtration, the Thames companies taking from the Thames on tide-water, which was at that time subject to the entire sewage-impurities of the city, as well as of all places above it on the banks of the Thames, or of the Lea, which found it convenient to pour their sewage into these rivers or their branches. The epidemic of 1848–9 left the conviction—without, it may be said, absolute proof—that its severity was more or less due to the impurity of the water-supply, and a law was passed, in consequence, requiring all the Thames water companies to take their supplies from a point above tide-water and above London, and to have the water sufficiently filtered before delivering it to the city. A certain period of time was given the companies to make this change and to construct the proper filtering works. The cholera visitation of 1853–4 found certain portions of the city supplied with filtered water taken from the Thames above the city and above the influence of the tidal flow, and certain portions still supplied as before; some of the water-companies having managed in the interim to change their point of in-take to a position up the river, beyond the influence of the sewage of the city, having made provision at the same time for the settling and filtering of the water; while others of the companies had not yet effected the required change of location, nor completed the necessary filtering works.

This cholera epidemic of 1853–4 showed very distinctly that in those parts of London where the filtered water taken from above the influence of the sewage of the city was used, the epidemic was very much less malignant than where the more impure water was used, taken from within the influence of the sewage of this great city. The General Board of Health took some pains to gather the statistics illustrative of this fact. Mr. J. Simon, F. R. S., in his report to the Board, made in May, 1856, selects the two water companies for comparison which were supplying the same class of houses, and as near as may be the same kind of population; the pipes of the two companies for a portion of their districts being laid in the same streets, each supplying about the same proportions of the houses in these streets. The one, the Lambeth, was delivering, in 1853–4, good water, speaking comparatively, from the Thames at Ditton; the other, the Southwark and Vauxhall, delivering bad water from the Thames at Battersea, as in 1848.

"Commonly, in attempting such inferences, the inquirer is baffled by difficulties which render exact conclusions impossible; for populations drinking different waters will often be living in different circumstances of wealth, comfort, occupation, cleanliness, soil, climate."

"In reference to the comparison which had to be made, it is especially important to observe that the tenantries of these two great companies were not set on different parts of the South London area, each isolated from the other. On the contrary, the two populations were, so to speak, mutually interfused. Of thirty-one sub-districts into which the large space is divided, only eight were monopolized by a single water company; while of the remaining twenty-three, each was supplied sometimes in equal proportion by one company and the other."

"In the 24,854 houses supplied by the Lambeth Company, comprising a population of about 166,906 persons, there occurred 611 cholera deaths, being at the rate of thirty-seven to every 10,000 living. In the 39,726 houses supplied by the Southwark and Vauxhall Company, comprising a population of about 268,171 persons, there occurred 3,476 deaths, being at the rate of 130 to every 10,000 living."

"The population drinking dirty water accordingly appears to have suffered three and a half times as much mortality as the population drinking other water."

"But this evidence is only a part of the case; it admits of being greatly strengthened by a second group of facts which the statistical tables exhibit. It was thought proper to see how far any discoverable influence of foul water had been constant to both occasions; and this comparison is of singular interest for our purpose, because the Lambeth Company, which in 1854 gave the superior water, was in 1848–9 purveying even a worse supply than that of the Southwark and Vauxhall Company."

"It has already appeared that the tenantry of the Lambeth Company lost by the epidemic of 1853–4 611 persons. By the epidemic of 1848–9, in the same houses (or rather in as many of them as then existed), the deaths were 1,925."

"The earlier figures showed that this population suffered in 1853–4 not a third as much as its neighbors; the present figures give the further fact that it suffered also not a third as much as at the time of its unreformed water-supply."

"Since the epidemic of 1853–4, the Southwark & Vauxhall Company, in obedience to the Metropolis Water Act, has abandoned its former very objectionable source of supply, and for the last few months [May, 1856] has been distributing a water nearly or quite identical in quality with that spoken of as furnished by the Lambeth Company."

"It entirely consists with the facts here set forth to maintain that, under the specific influence which determines an epidemic period, fecalized drinking-water and fecalized air equally may breed and convey the poison, and that this, whether in one vehicle or the other, may be expected to prevail most forcibly against the feeble and ill-nourished parts of a population."

It may be added that the evil effects of much-polluted water as compared with water but little polluted, which become so palpable and distinct in a time of epidemic, cannot cease to exist except in degree when no epidemic prevails. According as the river-waters are cleansed from the impurities which now are expected to hide themselves there, the general health of all living things depending on them and using them, whether in the shape of drink or food, must be benefited.

The cholera reappeared in London in 1866, June, July and August, and called attention again to the character of the water-supply by the "explosion," as it was called (from the sudden and fearful increase of deaths), in that district of

London supplied from the pipe-mains of the East London Water Company.

This company derived its water from the River Lea, at a point above Tottenham Mills. The water there passes into large open settling reservoirs. Moving slowly through these, and depositing there the heavier portion of any impurities in suspension, it is carried by an open canal about three miles in length, to the filter-beds below Lea Bridge. After filtration it is carried by a four-foot pipe, two miles in length, to the pumping station at Old Ford, where it is received into two covered reservoirs in communication with the pumping engines there. It is to be noted that there is one large pumping engine at Lea Bridge on the site of the filter-beds. At Old Ford there are four pumping engines.

"Of the total mortality from cholera in this visitation, of 5,548 souls, no less than 3,909 occurred in the East Districts alone." The population in this case will be a better indication of the condition than the relative area. The population of London for 1866 was 3,037,991; the population of the East London Districts was 598,945, leaving 2,439,045 for the rest of the metropolis. "No relative development of like magnitude, suddenness and shortness of duration has occurred in previous outbreaks of cholera in the metropolis." Nor are we able to trace the great excess of deaths to density of population. "In the recent outbreak, as in previous outbreaks, there was no relation between the density of population as expressed by numbers of persons per acre and the intensity of prevalence of the disease."

The following table shows the weekly deaths:

(*See Table next column.*)

The exaggeration of the death-rate over the ground supplied by the East London Water Company led to the suspicion that the water must be in fault. At Old Ford, beside the two covered reservoirs receiving the filtered water from Lea Bridge, there were two uncovered reservoirs full of unfiltered water; that water being likewise decidedly more impure than the water drawn from the Lea at the point of intake four miles up the river. The water in these uncovered reservoirs was drawn in part directly from the Lea near by, by soakage. "The river at this part of its course, in June and July, 1866, was a cesspool as well as a canal, for it then received the sewage of the large population inhabiting Old Ford, and the greater portion of Bromley and part of Mile-end." One of the covered reservoirs had a connection with the open reservoirs, and when the filtered water was deficient, the unfiltered water could be drawn from the open reservoir to meet the requirements of the pumps. It was ascertained that some water from these open reservoirs had been used, and to this mixture of a water, which, beside being unfiltered was in other respects much less clean, with the ordinary supply, this exaggeration of the cholera in this district was ascribed. The amount of bad water used seems to have been small, and yet the effect was fearful. Mr. Radcliffe believes that the fecal discharges from some cholera-patients emptied into the Lea there, reached and affected the waters of these open reservoirs.

CHOLERA OF 1866. WEEKLY DEATHS.

Week ending—	In the East District (598,945 population).	In the rest of London (2,439,046 population).
July 7	9	5
" 14	20	12
" 21	308	38
" 28	818	86
Aug. 4	916	138
" 11	673	108
" 18	369	86
" 25	198	67
Sept. 1	122	76
" 8	74	83
" 15	77	105
" 22	56	94
" 29	55	122

In corroboration of the belief that the water at Old Ford was contaminated in this way, and was the cause of the explosion of disease, the water delivered by the pumping engine at Lea Bridge, drawing its water directly from the filter-beds, did not produce this effect over the ground supplied by this engine.

The mixture of impure water at Old Ford had occurred frequently before with no perceptible effect on the population supplied. It was only on the occasion of an epidemic that the additional impurity made itself understood. Have we not reason to infer again that, as the waters furnished to London become less polluted than they are now, the general salubrity of the place will markedly improve, and the visits of an epidemic become less and less severe?

All that has been said thus far, although at times apparently contradictory, may be epitomized as follows:

To those who are willing to risk a certain measure of river-pollution, and who would disregard the warnings of epidemics, the London supply from the rivers Thames and Lea, can be referred to and quoted as being sufficiently safe for all uses, in healthy times, and under careful management and filtration, notwithstanding the pollutions to which these streams are known to be exposed.

To those on the other hand who would not expose the public health to any risk that can be avoided, and who believe that the gradual emancipation now in progress of the rivers Thames and Lea from sewage and other impurities will certainly improve the health-rate of that metropolis, and defend it measurably from those exceptional visitations of sickness, from which we can never expect to be wholly exempt;—to such, it is believed that the same course, as far as practicable, should be pursued with regard to the rivers of Massachusetts, and that pollutions of all kinds should be, as far as possible, prevented hereafter from passing into them, and that the fluid pollution now flowing into them should be intercepted and deodorized as far and as speedily as may be practicable; so that the waters may be gradually restored, and held, to that amount of cleanliness at least, which will admit of their being used as fair river waters are used in the arts and manufactures, in which fish will live and thrive, and which animals will not refuse, although the restoration might not always be sufficient to make the water safe for domestic use.

It is to be remembered of the rivers that rise within the State, that their waters are small in volume as compared with the Thames River. They have, besides, more fall per mile; present more frequent opportunities for water power; are much more occupied generally by mills for their volumes of water, and will therefore have a denser manufacturing population on their banks. The refuse from the various fluids of factories may be expected speedily to render these rivers (of small volume in summer) unfit for use, and in this respect far below the standard of the Thames water.

Some of the smaller rivers in England, as the "Ribble," and the "Calder," have run this course, are now black from manufacturing pollution, and have been long unfit for any domestic use.

Part III.—General Conclusions.*

In comparing, as has been done, the waters taken from the head and foot of each river, so to say, and from intermediate points, the inferences which have been drawn, or which could be drawn, from these chemical examinations, are not to be considered as expressing the whole truth; but only that part of it which analysis can reach; the exact influence or even presence of the sewage and trade-pollutions which may have passed into a stream cannot be discovered by the chemist, when minute in quantity. The poisons may be so largely diluted as to be beyond the readings of analysis, and yet they may be sufficient, when fairly presented and understood, to render the water, by reason of that knowledge, not merely repulsive or suspicious, but more or less dangerous for family use.

The opinion of the English Rivers-Pollution Commission was very decided on this point at the date of their writing (1868): "No process has yet been devised of cleansing surface-water once contaminated with sewage, so as to make it safe for drinking." And again: "Among the numerous processes for the cleansing of polluted water with which we have been acquainted, there is not one which is sufficiently effective to warrant the use for drinking of water which has once been contaminated with sewage or other similar noxious animal matters."

If this view of the case may seem to be over-cautious, it is to be remembered that the poison, however trifling, is taken daily, and that although when in robust health the individual will not suffer from it, it may be sufficient to make itself felt when he is prostrated by sickness

* The portion of the Report which presents the results of examinations of Rivers and Ponds is necessarily omitted for want of room.

and his powers of resistance to such influences are then proportionally impaired.

We have therefore, as Dr. Frankland says, always to ascertain and keep in view the character of the stream as regards exposure to pollution, and, if it has received much filth in its course, to consider its waters objectionable and to be avoided if possible for human use; unless, indeed, the volume of the stream should be so great, compared with the filth-pollution, as practically to be independent of such reasoning.

As an instance confirmatory of these remarks, take the water of the Blackstone River at the point where it crosses the state line, near Blackstone.

The river reaches this point, carrying with it the sewage of the city of Worcester, the refuse waters of thirty-six woolen mills, twenty-three cotton mills, six iron-works, a tannery and a slaughter house,—these works employing 7,200 hands, much of whose ablutions and sewage passes into the river.

The sewage of Worcester may be taken at a minimum per day of....................	2,000 000	gals.
The sewage of the mill operators and their families, at...	36,000	"
The fluid refuse of the mills it is difficult to estimate even approximately; it was estimated by the assistant engineer at 2,678,000 gallons—say,	2,500,000	"
Gallons per diem........	4,536,000	

Equal to 606,508 cubic feet per diem.

At Blackstone, the dry weather-flow of the river is taken at 5,961,600 cubic feet per diem.

This last includes the polluted waters as above estimated. We have therefore in this case, 5,355,092 cubic feet of unpolluted water mixed with 606,508 cubic feet of badly polluted water.

The sewage and refuse waters delivered into this river amount, then, by this estimate, to a little over ten per cent. of the average dry-weather flow of the stream at Blackstone, a degree of contamination which will be admitted to be condemnatory of that water; but, when the sample of water was taken for analysis (July 10), the river was not at its lowest summer stage, which generally occurs much later in the season. The flow in the river was not gauged at the time that the sample was taken for analysis, but its rate at that time might probably be about double of the dry-weather flow of a low season of rainfall, which would reduce for that date the proportion of the Worcester and trades sewage to over five per cent. of the volume of water running at Blackstone.

None of the rivers examined by us have this season reached the low stage of water referred to; they have all been in a low summer stage when the samples of water were taken, but not exceptionally so; and yet this exceptionally low stage must be encountered, sometimes for months, during very dry years. The pollutions received must, then, be applied to this measure to understand the degree of foulness to which the stream will be subject, noting, however, that during the very dry stage referred to, while the pollution from sewage will not be reduced, the pollutions from trades' refuse will be diminished considerably, whenever for want of water the factories are obliged to intermit or work half-time.

The analysis fails to show much difference between the water of the river at this point and its head waters—not enough to condemn the water for domestic use or any other use; but if you mix five per cent. of sewage-water with ninety-five per cent. of unpolluted river-water, the chemist could hardly fail, we should suppose, to discover some evidence of pollution. If this be so, we cannot avoid the inference, notwithstanding what has been said, and notwithstanding the opinions of eminent English chemists, that in the course of its movement over some twenty miles of the river channel, the sewage fluids in this case have lost some of their impurities, and that the analysis is not entirely at fault in encouraging this inference.

Of our rivers enough has been said, now and heretofore, to show that any defence of their waters against the impurities which so conveniently flow into them from the settlements and works on their banks, has thus far been merely nominal; that is, the law can be used to prevent a nuisance from continuing to be poured into the river, but it is not used because the process is too slow, cumbersome and expensive.

To change this state of affairs, and to

remedy it radically, is the problem now presented; and, while those who have been obliged to study the subject are confident that it is not insoluble, it is full of that kind of difficulty to overcome which will demand great perseverance, some experimenting, and, it may be, considerable invention and ingenuity. Not that there has not been much done in Great Britain to give direction to whatever may have to be done here, but our severe winter climate presents a difficulty by itself which will require special treatment; and, while there appears to be nothing insurmountable in dealing with it, it will probably add to the expense of all the purifying processes necessary to meet the different kinds of pollution to be dealt with. Every process will have in some degree to be tentative on this account, until the simplest and most economical mode of meeting the case is reached.

The Prevention of Pollution.

The law requires the Board of Health "to devise a system by which said rivers, estuaries and ponds may be protected against pollution, so far as possible, all with the view to the preservation of the health of the inhabitants of this Commonwealth."

To devise and perfect a system as varied in its modes of action as the fluid impurities emanating from the different kinds of works and from ordinary sewage will require, must, as has been hinted above, be a work of time; and, while authority must be lodged somewhere to begin this work, and probably to expend some money in ascertaining sometimes how to begin, it seems obvious that the authority given, should, in fairness to cities and manufactories, be exercised in the first instance only conditionally, and that in the case of any fluid impurities requiring to be stopped from entering the stream and to have their poisonous qualities destroyed, and the residue rendered innoxious before being passed into the stream, the authority having the power to require this course should be required to show how it can be done, and the apparatus or material required to effect it. In other words, that authority must be prepared to indicate or teach the mode of purification before taking legal action against it, the party required to act in the particular case being, however, at liberty to follow any process which he may prefer having in view the same end.

It may be further remarked in this relation, that the authority indicated should have the power to interfere with the pollution by steps, if advisable, perfecting such processes thereafter as circumstances admit of it. This might operate better than attempting that thoroughness of purification which may be practicable at once, inasmuch as entire purification will not probably in any case be attainable.

It may seem out of place in this paper to notice this phase of the subject, but its consideration is not easily avoided, and the allusion to it grows naturally out of the subject.

As an instance of the kind of difficulty which will have to be studied and overcome, the application of sewage to irrigation may be mentioned. Of all the modes of dealing with sewage, this may be said to be the favorite, inasmuch as it undertakes in a more simple way than any other to apply the fluid sewage upon land so as to make it as largely remunerative as possible. But there are two kinds of irrigation in this connection—the irrigation which, whether using water or sewage, applies it to the crops only as required and in quantities calculated to produce the best results. This kind of irrigation may be said to be always profitable; but, in this case, what is not wanted is not purified, and the overplus of that which has been used is not purified, although it has been somewhat deprived of its noxious qualities.

The other kind of irrigation is that which has in view, not merely the utilization, but also the absolute purification of the sewage-water. In this case there must be, first, such a liberal extent of land provided as will admit of the sewage during the growing season, at least, being entirely used by the different crops, arranged to that end. The process of irrigation, to produce the best results, being always intermittent, the grounds are broken up into many divisions or plots (the circumstances prescribing their size and number), so that the sewage-fluids can be transferred at will from one plot to another, or from one kind of crop to another; and there would want to be some idle plots, so to say, upon which the sewage could be thrown at seasons when it was in excess of what the growing or maturing crops required. The reader will understand that in the process of irrigation a certain portion of the fluid will settle into the ground ; and it is desirable that the ground should be of such a free and open character as to admit of this and to encourage it; for it is this earthy filtration supplementing the action of roots of the growing crops which deprives the sewage of its noxious qualities, and renders what is left of it fit to escape into the neighboring brook or stream. If this character of ground is not present, if the irrigation field has a heavy or clayey soil, deep drainage will enable it to produce the same cleansing effects ; but the ground must be high enough to admit of this drainage-water, thus purified, escaping freely into some neighboring stream. To this, the most favorable view of irrigation as a means of entire purification, there are two exceptions, and under a negligent manipulation of the process there would be more ; these are, first, the storm waters, which at certain times will make the delivery through the sewers so large as to render any reasonable extent of irrigation-fields incompetent for the time being to meet the excess, which cannot be allowed to flood the field, but must be otherwise taken care of ; the second exception is the winter, when for some months, it may be, the irrigation-fields will become useless as such. Beginning with what can be done, the difficulties which these exceptions present will gradually solve themselves, and it would be needless now to speculate upon the precise way in which this will be accomplished.

Dr. Folsom's report of how this has been met in Northern Europe will throw some light on the matter. When a beginning is made, however imperfectly, the necessities of the case will create the ambition to remedy what is amiss or incomplete, and some satisfactory solution of this difficult problem will in all probability follow.

It will be thought by some that in the winter the sewer-fluids might be passed into the stream without rendering its waters so objectionable as in summer; but the reverse is said to be the case : the gases which escape from the sewer-deposits in summer from over the entire surface of the stream are sealed up in winter, so that by breaking a hole in the ice the bad odor is made perceptible by this kind of concentration in winter, when in summer the sense of smell does not reach it under ordinary circumstances. The winter water is therefore more dangerous than the summer water except that, there being generally more water flowing in the river then, the poisonous fluids entering it will be more diluted.

It is probably true that no process or combination of processes for the sufficient purification of sewage-waters has ever produced results which collectively made it remunerative; the precipitate collected by most of the patent processes will always sell for something for farming purposes, and where irrigation is used besides, crops will be large and have commanded good prices, but the adjuncts (whether of land for filtration or otherwise) necessary to destroy the whole of the filth more than eat up the profits. It is a great advantage and encouragement to be able to reduce the cost of this kind of purification; but to attain the desired result without any outlay, far less to make it a means of profit, is not, in the present state of our knowledge, to be expected.

The ground below Worcester is understood to be very favorably situated for irrigation, and the soil and subsoil to be of the right character as well for filtration. There will be a good opportunity, then, to deliver the Blackstone River from this its greatest concentration of pollution, and to experiment on the kinds of winter appliances that will be necessary in combination either with irrigation or filtration.

Drainage and Sewerage.

We now come to the second branch of the subject in the order in which it has been presented here, although in the discussion of the first it has been impossible to avoid touching on the second.

The law requires the Board of Health "to investigate the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth, and to devise and report a system by which said cities and towns may be properly drained."

To devise a system which, within the compass of a report of this kind would be applicable in its details to all cities and towns would be impossible; every city or town must be the subject of a separate study by a competent engineer, founded on a correct and minute survey of the streets or ground to be drained or sewered, with correct levelings of the whole.

The law evidently did not intend this construction to be put upon it, but it may have expected that some general principles should be presented controlling this part of the subject. Such general principles will govern each case, but to prescribe any special mode of carrying them out might be burdensome where all the State is interested in the result. Some points, however, may be noticed that are independent of any particular working system, or common to all of them.

In Europe, the drainage of the subsoil by a separate provision of drains, apart from the usual system of sewers to carry off the house-refuse, has been advocated, and there may be places where from the character of the subsoil or the amount of water present in it, such a double system would be desirable; but it has not found favor in this country, nor are we aware that it has been anywhere found necessary;* the increased cost of any such double system, and the inconvenience to the streets growing out of its proper maintenance, would always be barriers to its adoption.

The proper drainage of the soil is always very important, but, except where the water is held up by a neighboring river or lake or by tide-water, the trenches made for the sewers in our cities evidently act more or less as blind drains to keep it down.

This drainage of the subsoil, following as it frequently does the construction of sewers, if obtained at all through that defective construction which admits of leakage *into* the sewers, will do no harm while that leakage is moderate in amount, and consists of subsoil water escaping *into* the sewers. But the engineer will note that the same defective construction would admit of leakage from the sewer into the subsoil, when the subsoil-water happened to get below the level of the sewer, and that in this case the evil following a leakage outward would be twofold : the subsoil would be rendered filthy and might infect the neighboring cellars, and the fluid necessary to the flow of sewage-matters, if lost in this way, would lead to deposits within the sewers of the heavier matters, very objectionable there in every way.

For the continued and perfect action of the sewage, therefore, under all circumstances, the sewer should be so constructed as to be tight, and not leaky, unless the circumstances make the other course very clearly desirable. It is not difficult to make concrete sewers tight, if made with Portland cement concrete, or its equal; nor is it difficult, with proper attention to the joints, to make a pipe-sewer tight, nor a brick-sewer, if the engineer is determined to have it so.

The neglect of deep-soil drainage in the country at farm-houses, isolated dwellings of any kind, or villages, must be the cause of more sickness than any defects in the condition of the waters used there. In cities, the sewer-drains, or trenches, which are always deep, to some extent, take care of it, and, where they do not, the damp or wet cellars make the danger known, and show the necessity then of some separate provision to keep down the subsoil water. In those streets of a city which lie on a river bank, subject to floods, or upon the seaboard, as Boston, where the tides rise from eight to ten feet, both the drainage and the sewerage, as ordinarily provided for, are liable to serious interruption; in the first case, irregularity; in the second case, daily. To provide, if possible, for the uninterrupted flow of the sewage, is always important. It is very important that that flow should not at any time be brought to rest, because then the heavier portions will become deposited, and will accumulate and fester so as to generate the dangerous gases which belong to putrid sewage, but which in the case of fresh sewage are merely offensive. It is desirable always that the sewage generated in a city should leave the city on the same day, within twelve hours at most, and that it should never be retained long enough to become putrid. The drainage

* It has been used for some years in three towns of England.

in such exceptional cases would be a more difficult matter, and it would probably be cheaper in most cases to keep all streets and dwellings situated well up above tidal influences, than to attempt to keep down the subsoil water. But the interruption of the sewage-flow is another matter; it leads to a filthy deposit growing with each day, and which cannot be removed by the rate of original flow which would have kept it in motion to the pump-wells, and prevented its deposit. If it is allowed to subside and get firm, it can only be carried off thereafter at intervals by storm waters, or by flushing, or by manual labor; in either case after it has become very offensive. Under such a state of things, ventilation becomes very important. It is conceded that the impure air of sewers should rather be allowed by frequent shafts to escape into the street, than be driven into the houses, as it will be more or less, if no other *outlet* is provided for it.

Of the sewage proper, the Board of Health is required "to report how far said sewage may be utilized and disposed of."

The utilization of sewage by irrigation has already been dwelt upon, and the auxiliary works which may have possibly to accompany irrigation wherever the intention is as well to render the sewage-fluid, or its residues innocuous.

The utilization separately of the precipitates from sewage has been and is in many patent ways accomplished, but the fluids are not entirely deprived of their baneful qualities, and are reported to be unfit to pass into a river. None of these processes are remunerative when the other condition of rendering the fluid residue sufficiently pure as well as clear is insisted on. It is to be remarked of all these precipitates from sewage that, except when mixed with lime or some other equally valuable ingredients, they are all but worthless for manure. To make them salable for agricultural purposes, they must be enriched with foreign ingredients, without which the offensive solids of the sewage could not be got rid of.

The attempt is being made in some places on the continent of Europe, with a good deal of success, to keep separate the human excrements, and not allow them to enter the sewers, withdrawing them separately from the houses while fresh, and in various ways preparing them for agricultural use. It is obvious that if this could be accomplished, the kitchen fluids, the trades and the street refuse would be somewhat more easily and more willingly dealt with. The human refuse, although trifling in *degree*, compared with the mass of fluid which flows through a sewer, is yet sufficient to give it much of its offensive character, and to produce, when the sewers are neglected, many of the offensive odors and gases that are believed to be dangerous to health. The separate mode of disposing of human excrement is, however, repugnant to our habits here, and therefore, both here and in Great Britain, the water-closets and the removal by water of all human refuse is greatly preferred.

The most successful modes of dealing with sewage at this date, as well as with other pollutions which at present are rendering the waters of our streams so objectionable, are explained in the separate report of Dr. Folsom, who has devoted the past season to an examination of such operations in Europe. When it shall be necessary to act, we have thus the benefit of a large and varied European experience. Much of it can doubtless be assimilated here, with such additions or modifications as will meet the rigor of our winter climate.

LOCOMOTIVE TORPEDOES.

From "The Engineer."

One of the most remarkable phases of modern warfare is the employment of mechanical powers to transport explosives to the precise locality where they can prove most mischievous to an enemy. In the days of Nelson, ships fought with carronades, stumpy guns of considerable calibre, which pounded the wooden walls of a ship to atoms by a hundred blows. The duty performed by the Victory's artillery was identical with that performed by a Roman battering ram. In the field, again, Napoleon relied on the round shot, which, as we are graphically told by the historians of the time, mowed lanes through the columns of an advancing foe. Grape was used at sea, or on land, only at close quarters. It was practically useless in naval warfare, save in resisting boat attacks, or covering the landing of troops, while its short range and unequal dispersion greatly limited the scope of its powers when it was used in land battles. To the American general Paixhans is, we believe, due the credit of first employing shells in naval warfare. In saying this we do not forget the labors of Cohorn, and we are not oblivious of the circumstance that "bomb ketches," as they were termed, existed and were used from a comparatively early period. But to General Paixhans belongs the credit of using guns which threw shells directly into a vessel without going through the ceremony of first letting them rise high in the air, and then fall, if chance so directed, on the deck or down the hatchway of a ship. The process of development has gone on steadily for very many years, and modern naval artillery relies principally on the effect of shell fire for its efficiency.

The 80-ton gun, for example, would be comparatively a very useless weapon if it could project against our enemies' ships only solid shot. A mass of iron weighing 1700 lb. tearing through a ship's side above the water line, and clear of engines and boilers, would do but little injury, save of a purely local character; and a great many successful rounds would have to be fired from the great gun before even a wooden ship to which the weapon was opposed need succumb. But in point of fact the chilled shell proper contributes only indirectly to the destruction which a heavy gun can accomplish. The object and purpose of modern naval artillery is to transport from the decks of one of our own ships to the decks of an enemy a heavy charge of powder, which is ignited at the moment of its arrival. If the shell explodes outside the ship, although in contact with her, half its efficiency is gone. A shell, after all, is but a transport wagon carrying a charge of powder; and that shell and that gun are the best which place the transmitted charge of powder just where it can be exploded with the most effect. It will be seen, therefore, that we have here a total change in the purpose of artillery; and it follows that if the explosive could as well be put on board an enemy's ship by any other means as by the use of a gun, then guns would be comparatively useless. The shell is *the* great engine of modern warfare. In olden times the gun took the place. The modern gun is, however, merely an energy transmitter, and in so far it occupies a secondary position.

A little reflection suffices to show that we are not confined to guns as the only means of transporting explosive charges to an enemy's decks. Various other plans have been suggested. The late Lord Dundonald proposed during the Crimean war that about a gallon of chloride of nitrogen should be carried up over Sebastopol in a balloon and then suffered to fall into that town. The resulting explosion would, no doubt, have cleared Sebastopol, its fortifications, and its fleet, off the face of the earth. The scheme was wild to the last degree. The explosion of a single drop of chloride of nitrogen has been known to completely ruin a large laboratory; and it is tolerably certain that more than a few drops of the most terrific compound that has ever existed have never been made. The use of balloons for dropping shells into an enemy's camp has often been proposed, however, and not many years since a somewhat eminent authority suggested the use of an improved form of the old Roman catapult for flinging grenadess and small shells into an enemy's trenche. Powder wagons provided with a slow burning fuse have been purposely suffered to fall into the hands of an enemy, who, removing the wagon to his own lines in triumph, has subsequently suffered severely for his rashness. Such a practice would hardly, we may say for the credit of humanity, be recognized as legitimate in modern warfare, although there is reason to believe that infernal machines assuming the form of blocks of coal have not only been suggested, but actually manufactured. The diabolical scheme of Thomas, which must be fresh in the memory of our readers, supplies another method of placing explosives on board a ship or in some other locality where they are intended to effect destruction. All such schemes, however, have hitherto possessed but a fifth-rate importance as compared with the gun, which above and beyond all other agencies puts in the hands of the sailor or the soldier the means of lodging his shell just where he pleases. There is reason to believe, however, that the gun will not retain this absolute and overwhelming supremacy; and indications are not wanting that in the immediate future means will be provided of effecting all that the heaviest gun could accomplish in this way and a little more. We allude, of course, to the locomotive torpedo—a weapon with probably a great future before it.

So long as the torpedo was an anchored submerged buoy its utility was limited. The ship which it was intended to destroy had to go to it, and so long as it was left alone it would do no one any harm. The Harvey torpedo and the steam torpedo boat both enormously increased the power of the weapon; they each conferred on us the power of transmission; it became possible to take Mahomet to the mountain, as the mountain would not go to Mahomet. But it is obvious that very grave objections exist to both systems of attack. The torpedo launch can only be manned by volunteers who go on a forlorn hope. Not only can they expect no mercy from foes whom they must, in the nature of things, attack insidiously, but they run the risk at the best of times, when they are most successful, of sharing destruction with their enemies. The vessel towing a Harvey torpedo is again in much the same plight, and it is probably true that if several ships were operating together, the use of a Harvey torpedo by one ship might severely hamper the movements of her consorts, who would be compelled to give her a tolerably wide berth. The so-called fish torpedo promises to fulfil every condition that an engine of the kind can be called upon to perform. It is truly a locomotive torpedo, and is the most recent embodiment of the system of carrying on board—or into immediate proximity with a foe at a distance—the explosive charge which is to work her destruction. We say this with a perfect cognisance of the imperfections of the Whitehead torpedo. But we are, at the same time, in possession of facts which tend to show that it is susceptible of very important and valuable improvements. A great deal of money has been expended by the British Government on the invention since it came into their hands; and although a very commendable spirit of reticence restrains the official pen, enough is known to enable us to say that the range of the weapons has been so enormously augmented that it probably equals that of a very heavy gun, instead of being limited to a mile or so, while the difficulties which have been encountered in guiding it appear to be one by one disappearing in the hands of the intelligent officers who have charge of the invention. The Whitehead, or, more strictly speaking, the Woolwich torpedo, is now really a submarine boat, some twenty-five feet long, capable of running a distance as great as from Portsmouth to the Isle of Wight, the direction of its motion in still water being practically a right line.

It is evident, therefore, that for harbor attack it can probably be used with tremendous effect under certain circumstances. Thus an ironclad, by taking up a position at the mouth of a large harbor, and at such a distance that she would be practically safe from the guns of land forts, might, by sending in fish torpedoes, completely destroy a fleet taking refuge under the guns of the forts. The weapon might also be employed for clearing ground torpedoes out of a channel. In such a case it would assume a far simpler and cheaper form than that given to it when used to carry an explosive charge. The great difficulty to be overcome is to give it the power of always moving straight forward, exactly in the direction in which it should go; and this has been partly accomplished by very ingenious apparatus depending for its operation on the inertia of a suspended mass. It would be quite possible to use a gyroscope for the required purpose, but the difficulty would remain that if the deviating force be greater than the inertia provided can overcome, then the torpedo will assume a new line of motion, and resist any secondary deviating force as strongly as it resisted the first. We are not aware whether the principle of the gyroscope has yet been adopted in steering fish torpedoes; if not it ought to be tried, as it promises well. It does not seem to us, indeed, that any impassable obtacle exists to the construction of a fish torpedo or submerged boat, which shall possess automatic steering power sufficient to preserve a line sufficiently straight to insure that the weapon shall strike so large a mark as a man-of-war at moderate range. All that can be said certainly on such a subject, however, is that the locomotive torpedo becomes day by day more manageable; and it is not impossible that naval officers will soon be placed in possession of tables of deviation for their guidance when using the torpedo in a current. These tables would show, for example, if a ship to be attacked lay north of another at a range of say two miles, how many points to the west the head of the torpedo must be laid to provide for the effects of a current flowing at a given velocity in an easterly direction.

THE CALCULATION OF EARTHWORK.

By N. B. PUTNAM, C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE author (Mr. Davis) of the article, "The Earthwork Question," which appeared in the December number of this Magazine, has found in Simpson's Rule so formidable an obstacle to a fair understanding of my paper of last October, that it does not appear out of place to preface the present article with a short discussion of Simpson's Rule and the Prismoidal Formula.

A Prismoid may be defined as a solid contained between two parallel planes and composed of prisms, wedges and pyramids, whose common altitude is the perpendicular distance between the parallel faces. The rule for the solidity of a prismoid was first demonstrated, in later days, by Thomas Simpson, an English mathematician of the last century, and may be given as follows:

Simpson's Rule.—To the sum of the areas of the two ends of a prismoid, add four times the area of a section made by a plane parallel to and equi-distant from both ends; multiply the result by the altitude, and one-sixth of the product will equal the solidity.

This rule, which has been variously stated, is now generaly known by the name of the *prismoidal formula*, which, expressed in algebraic language, is

$$V=\frac{l}{6}(S_1+4\,S_m+S_2), \qquad (A)$$

V being the volume and l the altitude of the prismoid, S_1, S_2 the end, and S_m the middle areas. By dividing (A) by a we get

$$\frac{V}{a}=\frac{l}{6}\cdot\frac{S_1+4\,S_m+S_2}{a}, \qquad (A')$$

which expresses the area of the base of the equivalent prism of altitude a. Now it is well known that some bodies which are not prismoids may have their volumes expressed by the prismoidal formula; thus the volume of the sphere

$$=\frac{4}{3}\pi p^3=\frac{2\,p}{6}\,(0+4\,\pi p^2+0)$$

the areas of the bases of their equivalent prisms will then be given by the expression (A′). If, therefore, we determine those figures whose areas are given by (A′), we may the more easily determine those solids whose volumes may be found by Simpson's Rule.

In (A′) let

$$\frac{V}{a}=A,\ \frac{S_1}{a}=y_1,\ \frac{S_m}{a}=y_m,\ \frac{S_2}{a}=y_2,$$

then $$\frac{V}{a}=A=\frac{l}{6}\,(y_1+4\,y_m+y_2) \qquad (B);$$

now if $y_m=\frac{1}{2}(y_1+y_2)$, A will represent the area of a rectangle, a triangle or a trapezoid. Therefore those solids which have these figures for the bases of their equivalent prisms of altitude a, may have their solidities determined by the prismoidal formula; in other words, if the areas of the sections of a solid made by parallel planes be proportional to the ordinates of a right line the volume of the solid may be found by Simpson's Rule.

Among the solids of this class may be mentioned the prism, the rectangular wedge, and the paraboloid of revolution.

In (Fig. 1) let A be the vertex and o Y the axis of a parabola, and let o be the origin of co-ordinates; and let it be required to find the area $bb'c'c$ included

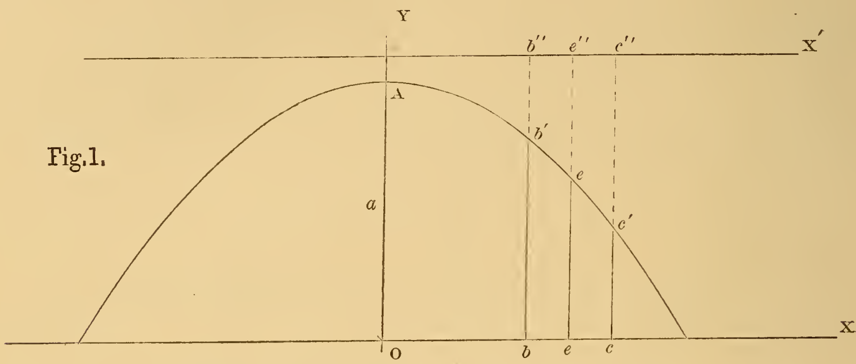


Fig. 1.

between the parabolic arc $b'ec'$, the axis of x and the two given ordinates bb', cc'. Put $oA=a$, $ob=x_1$, $bb'=y_1$, $oc=x_2$, $cc'=y_2$

$$oe=x_m=\frac{x_1+x_2}{2} \text{ and } ee'=y_m.$$

From the eq. to the parabola we have

$$x^2=2p\,(a-y), \text{ or } y=a-\frac{x^2}{2p} \quad . \quad . \quad (1)$$

the expression for the differential of the area is

$$dA=y\,dx=\left(a-\frac{x^2}{2p}\right)dx;$$

$$\therefore\ A=\int_{x_1}^{x_2}\left(a-\frac{x^2}{2p}\right)dx=\text{area } bb'cc',$$

$$A=\left(ax-\frac{x^3}{6p}\right)_{x_1}^{x_2}=ax_2-ax_1-\frac{x_2^3-x_1^3}{6p}$$

$$=\frac{x_2-x_1}{6}\left(6a-\frac{x_2^2+x_1^2}{p}-\frac{x_2\,x_1}{p}\right) \quad (2)$$

In equation (1) make $x=x_m$, then

$$y_m=a-\frac{x_m^2}{2p}=a-\frac{x_2^2+x_2\,x_1+x_1^2}{8p}$$

$$\text{and } 4\,y_m=4\,a-\frac{x_2^2+x_1^2}{2p}-\frac{x_2\,x_1}{p}.$$

Introducing $4\,y_m$ into equation (2) gives

$$A=\frac{x_2-x_1}{6}\left(2a-\frac{x_2^2+2\,x_1^2}{2p}+4\,y_m\right);$$

or, since $a-\frac{x_2^2}{2p}=y_2$ and $a-\frac{x_1^2}{2p}=y_1$,

$$A=\frac{x_2-x_1}{6}(y_1+4\,y_m+y_2)=\text{area } bb'c'c \quad (3)$$

which is in the form (B).

This expression may also be used to determine the area $b''b'c'c''$, $b''X'$ being now the axis of x. If, therefore, the areas of the sections of a solid made by parallel planes be proportional to the ordinates of the parabola of Fig. 1, the volume of the solid may be determined by the prismoidal formula.

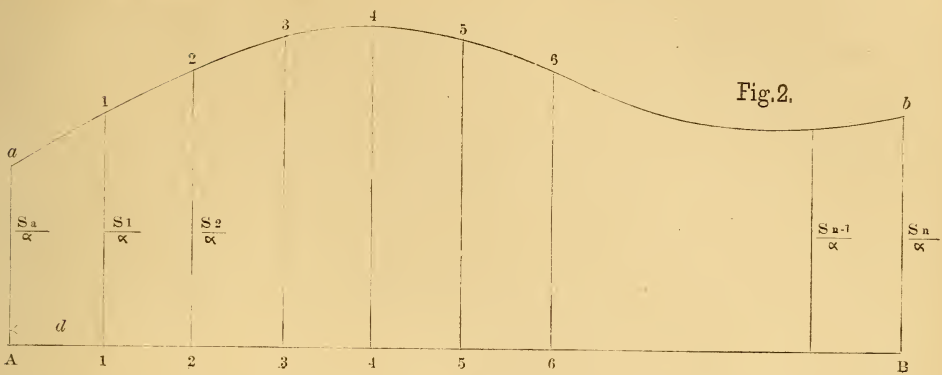
Among the solids of this class may be mentioned the double-edged wedge, the pyramid, the ellipsoid of revolution and certain warped solids.

Simpson's Rule, moreover, affords a convenient and very approximate method of finding the volume of an irregular solid, in which an odd number of equidistant and parallel sections are given. Let A B (Fig. 2) represent the length of such a solid and A a 1234....b B the base of the equivalent prism of altitude a; let the common distance between the sections be d. Consider any one pair of bands as 22344 into which the ordinates divide the base. The boundary line 234 may without material error be considered a parabolic arc; the area of this portion of the base may therefore be found by eq. (A′), and the corresponding volume by eq. (A). Beginning at A, we have

$$\text{Volume A}\,a\,122=\frac{d}{3}\,(S_a+4\,S_1+S_2),$$

$$\text{“} \quad 22344=\frac{d}{3}\,(S_2+4\,S_3+S_4),$$

$$\text{“} \quad 44566=\frac{d}{3}(S_4+4\,S_5+S_6), \text{ \&c.}$$



Adding we have for the volume

$$A\,a\,12345\ldots\ldots b\,B$$

$$=V=\frac{d}{3}\,(S_a + 4\,S_1+2\,S_2+4\,S_3+\;\ldots\;+4\,S_{n-1}+S_n)\quad (C)$$

This method, although more than a century old, is still the simplest and best at present known for approximating the area of irregular curves or the volume of irregular solids. It is to this "novel" method, when applied to the computation of earthwork, that Mr. Davis finds serious objection. He says: "The author is also led into the following great error: 'When the sections are equi-distant, the solidity of the excavation should be found by the prismoidal formula using measured middle areas; in other words, by the application of Simpson's Rule, substituting the cross-sectional areas for the length of the ordinates.'"

Since Mr. Davis objects to the use of the prismoidal formula, using measured, that is the actual middle areas, and at the same time kindly advise the author to cling to the prismoidal rule, it is difficult for one to determine whether he considers assumed middle areas more reliable than the actual ones, or has given to the formula a new and better application.

The following extract from Rankine's Civil Engineering, Art. 186, p. 329, requires no explanation: "Case II. *When three equi-distant cross-sections*, S_0, S_1, S_2, *are given, with the total length* X, *of the piece of earthwork between them*, the best approximation is

$$V=x.\frac{S_0+4\,S_1+S_2}{6}."$$

In the method usually employed for estimating volumes of earth, each of the blocks, into which the cross-sections divide an excavation or embankment, is regarded as a right-lined solid; upon this assumption its middle area is determined by means of the dimensions of the end sections, and its volume found by the prismoidal formula. Since the assumed middle area is usually less than the arithmetical mean of the end areas, the volume found by this method of calculation is less than that found by averaging the end areas. We may say, therefore, that the sections of a block of earth are proportional to the ordinates of a curve convex towards the axis of abscissas.

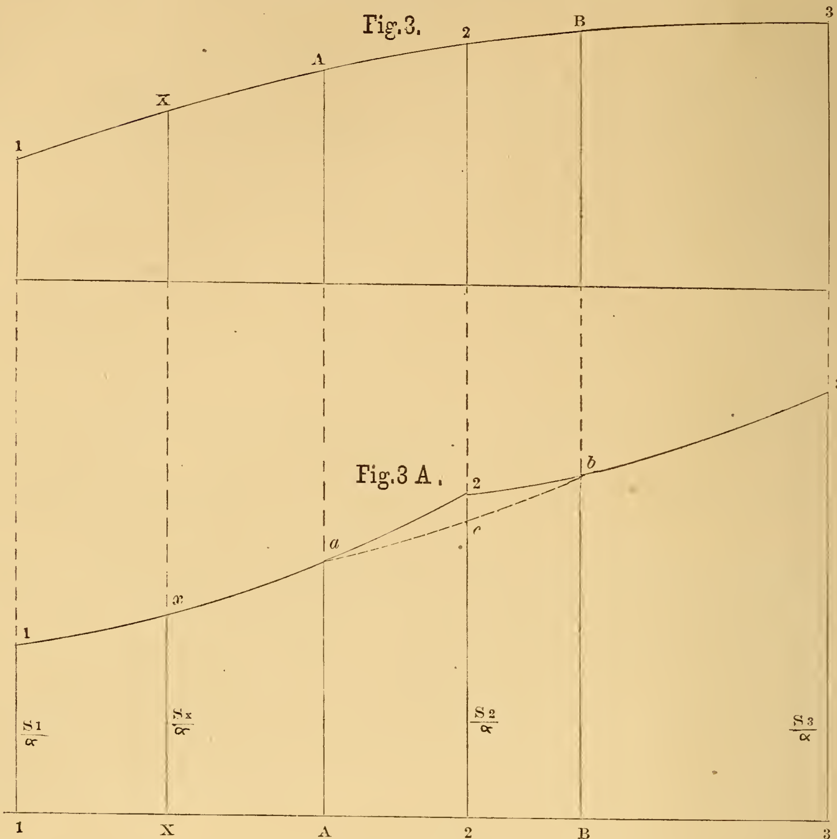
Let Fig. 3 represent the longitudinal section of a piece of earthwork given by the areas of the cross-sections at 1, 2 and 3. The solid is thus divided into two blocks of earthwork. Let the cross-sectional areas be respectively proportional to 1_1, 2_2, 3_3 (Fig. 3A), *i. e.* let

$$1_1=\frac{S_1}{a},\ 2_2=\frac{S_2}{a},\ 3_3=\frac{S_3}{a}.$$

Now, if the method usually employed be correct, these two blocks of earth are equivalent to a prism whose altitude is a, and whose base is $1\,{}_1\,a\,2\,b\,{}_3\,3$. From this base the cross-sectional area at any point of the solid may be obtained; thus the cross-sectional area at X is

$$S_x = X_x \times a.$$

Consider now the solid contained between the cross-sectional planes at A and B; the area of the cross-section at A is, $S_a = A\,a \times a$, that at B is, $S_b = B\,b \times a$. If the volume of this block of earth, as determined by the "*Method of the Prismoidal Formula*," be the true volume,



this solid is equivalent to a prism whose altitude is a and whose base is A $a\,c\,b$ B; as before, the area of any cross-section of the block may be found from the corresponding ordinate of this base. Thus $S_2 = 2\,c \times a$, but by construction $S_2 = 22 \times a$, whence $2\,c = 22$, which is absurd.

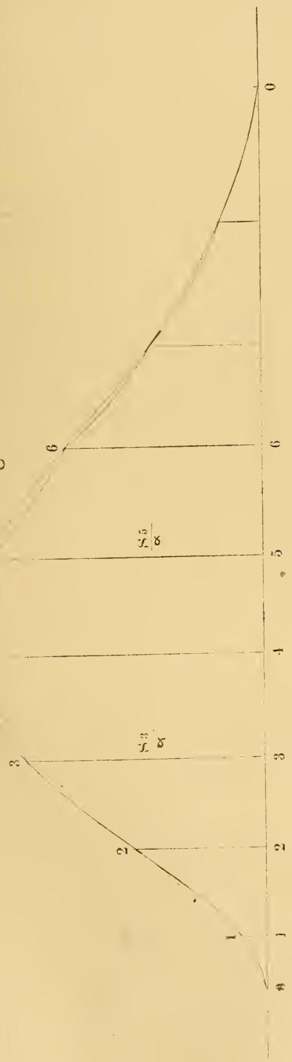
Whence we infer that the cross-sectional areas of a solid of earthwork are not proportional to the ordinates of the curve of Fig. 3A. We conclude, therefore, that a block of earthwork is not a prismoid, that the surface of the ground is not a surface of right-line generation, and that this method of calculation usually gives *less* than the true amount.

The failure of the "Prismoidal Method" to give true results, arises not from any inaccuracy of the prismoidal formula, which with the actual middle area will give the true volume, but is due to the erroneous assumption, that a block of earth is a right-lined solid. This fallacy is very apparent when we consider the forms of the longitudinal and cross-sections of a piece of earthwork; thus in the longitudinal section the surface line is always supposed to be straight, while in the cross-section, the surface line is generally broken into two right lines; yet the sum of the "distances out" is usually less than sixty feet, while the distance between the cross-sections, *i. e.* the length of the longitudinal section, is generally 100 feet.

The ground surface of a solid of earthwork is generally curved and always irregular; since the form of this surface is seldom if ever definitely known, the best and probably the only reliable approximation to the volume is obtained by regarding the piece of earthwork as an irregular solid. When such a solid is given by the areas of an odd number of equivalent cross-sections, the best approximation to the volume is given, as has already been stated, by a continued application of the prismoidal formula, using only measured areas. And there now remains to be considered the case, of more frequent occurrence, in which the blocks of earth have different lengths.

If, in an excavation or embankment, we measure the areas of the cross-sections at every foot of the length, and construct the base of an equivalent prism, we shall find that the form of this base, although depending to some extent upon the character of the ground, is that represented in Fig. 4; the bounding curve being convex downwards at the ends and concave downwards at the middle portion.

Fig. 4.



Let a piece of earthwork be given by the positions and areas of a number of cross-sections, let Fig. 4 represent the base of the equivalent prism of altitude a, and let the ordinates 1_1, 2_2, 3_3, &c., be proportional to the given cross-sectional areas. If now the volume of any block of the piece of earthwork be found by the mean areas' method of calculation, by joining the upper ends of the ordinates, corresponding to the given end areas, by a right line, we obtain the base of the prism whose altitude is a, and whose volume equals the estimated volume of the block. It is evident, therefore, that this method of calculation gives more than the true amount in the blocks of earth at the ends, and less than the true volume in the blocks at the middle of the earthwork. For a whole excavation or embankment the mean areas' method *seldom* gives *more* than the true volume. If the volume of a block be determined by the "*prismoidal method*," the base of the prism, of altitude a and of volume equal to the estimated volume, may be found by joining the ends of the ordinates, corresponding to the given end areas, by a curved line, convex downwards. This method of calculation, as is seen in the figure, usually gives *less* than the true volume of a block at the ends as well as at the middle of the earthwork; although at the ends it gives a close approximation to the true volume.

There is no method of calculation in present use which, at all times, gives even approximately, the contents of a solid of earth given only by its length and the areas of the end sections; and so long as the object of earthwork computation is to determine the volume of earth removed from an excavation or put into an embankment, there seems to be no reason why we should not deal directly with the solid in question in approximating the total volume, or why we should replace it by prismoids;—bodies which have no place in practical earthwork.

LARGE IRON PLATE.—Messrs Charles Cammell & Co., of the Cyclops Works, Sheffield, last year, rolled an armor plate 22 inches thick, 8 inches thicker than any armor plate ever before produced.

TRANSMISSION OF POWER BY WIRE ROPES.*

By ALBERT W. STAHL, M. E., Cadet-Engineer, U. S. N.

II.

Section V.

THE CATENARY.

If a rope or other flexible continuous line be secured at two points and loaded continuously between them according to any law, it will assume some definite curvilinear form. When the load is the weight of the rope only, the curve is called a "catenary."

Suppose that the rope is fixed at the points A and B (see Fig. 16), and that

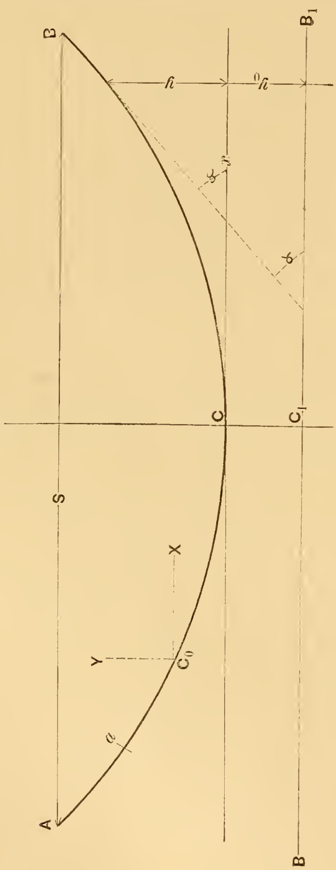


Fig. 16

the only force in operation is the weight of the rope, *i. e.* the load is a continuous and direct function of the length of arc. Take the origin of co-ordinates at any point on the curve (C_0), the axis of Y being vertical and the axis of X horizontal. All our forces being in one plane, the axis of Z is of course unnecessary.

Let t' = tension at any point, as a.

t_0 = tension at the origin C_0.

X_0 = horizontal component of the tension at $C_0 = t_0 \frac{dx'}{ds}$

Y_0 = vertical component of the tension at $C_0 = t_0 \frac{dy'}{ds}$

X = horizontal component of applied forces between C_0 and a.

$\frac{dx}{ds}$, $\frac{dy}{ds}$, will be the cosines of the angles which the curve makes with its respective axes, and resolving t' we have

$t'\frac{dx}{ds}$ = horizontal component of tension,

$t'\frac{dy}{ds}$ = vertical component of tension,

Consequently, from the principles of Mechanics, we must have, for equilibrium

$$\left.\begin{array}{l} X + X_0 + t'\frac{dx}{ds} = 0 \\ Y + Y_0 + t'\frac{dy}{ds} = 0 \end{array}\right\} \quad . \quad . \quad . \quad (18)$$

These equations are perfectly general for any case in which the applied forces are in one plane.

To get a more definite result for the case under consideration, we will take the origin at the lowest point C and the axis of X tangent to the curve at that point; this will make $\frac{dx'}{ds} = 1$ and $\frac{dy'}{ds} = 0$; as the weight acts vertically, $X = 0$. With these substitutions we get

$$\left.\begin{array}{l} t'\frac{dx}{ds} + t_0 = 0 \\ Y + t'\frac{dy}{ds} = 0 \end{array}\right\} \quad . \quad . \quad . \quad (19)$$

Let w = weight per running foot of rope,

* A graduating thesis at the Stevens Institute of Technology, Hoboken, N. J., June 30th, 1876.

and s=length of curve in feet; then ws= weight of the rope; and as this is the only vertical force we have ws=Y.

This reduces the above equations to the following :

$$\left.\begin{aligned} t'\frac{dx}{ds}&=t_0 \\ t'\frac{dy}{ds}&=ws \end{aligned}\right\} \quad . \quad . \quad . \quad (20)$$

Equation (20) shows that the horizontal component of the tension is equal to the tension at the lowest point, *i. e.*, the horizontal component of the tension is constant throughout the curve. We also observe that the vertical component of the tension at any point is equal to the weight of so much of the rope as comes between the origin and the point considered.

Dividing the first of equations (20) by the second, we get

$$\frac{dx}{dy}=\frac{t_0}{ws} \quad . \quad . \quad . \quad (21)$$

which shows that the tangent of the angle varies inversely as the weight of the rope.

Differentiating equation (21) we have $d\left(\frac{dy}{dx}\right)=\frac{w}{t_0}\,ds$, but $ds=(dx^2+dy^2)^{\frac{1}{2}}=\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}dx$. Substituting this value, we have, after transposing

$$\frac{w}{t_0}\,dx=\frac{d\left(\frac{dy}{dx}\right)}{\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}} \quad . \quad . \quad . \quad (22)$$

Integrating equation (22), we obtain

$$\frac{w}{t_0}x=\text{Nap. log.}\left(\frac{dy}{dx}+\sqrt{1+\frac{dy^2}{dx^2}}\right)$$

This may be written $e^{\frac{wx}{t_0}}=\frac{dy}{dx}+\sqrt{1+\frac{dy^2}{dx^2}}$; transposing, we get

$$e^{\frac{wx}{t_0}}-\frac{dy}{dx}=\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}$$

Squaring this equation we get

$$e^{\frac{2wx}{t_0}}-2e^{\frac{wx}{t_0}}\frac{dy}{dx}+\frac{dy^2}{dx^2}=1+\frac{dy^2}{dx^2} \quad . \quad . \quad (23)$$

Reducing and clearing of fractions, we get

$$dy=\tfrac{1}{2}\left\{e^{\frac{wx}{t_0}}-e^{\frac{-wx}{t_0}}\right\}dx \quad . \quad (24)$$

Integrating the above equation, we obtain

$$y=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\}+\left\{C=-\frac{t_0}{w}\right\}$$

$$\therefore\ y+\frac{t_0}{w}=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\} \quad . \quad (25)$$

which is the equation of the catenary. To bring this equation into a simpler and more manageable form, we will transfer the origin of coordinates to C_1, making $CC_1=\frac{t_0}{w}$. Then our new ordinates will be equal to $y+\frac{t_0}{w}$, so that the last equation may be written

$$y_0=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\} \quad . \quad . \quad . \quad (26)$$

But in making this change of origin, $\frac{dy}{dx}$, the tangent of the angle a evidently remains constant, and having previously found $\frac{dy}{dx}=\frac{ws}{t_0}$, we will substitute this value in equation (24), giving rise to the following value for the length of arc:

$$S=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}-e^{\frac{-wx}{t_0}}\right\} \quad . \quad (27)$$

Squaring equations (26) and (27), we get

$$y_0^2=\frac{t_0^2}{4w^2}\left\{e^{\frac{2wx}{t_0}}2+e^{\frac{-2wx}{t_0}}\right\} \quad . \quad (26a)$$

$$S^2=\frac{t_0^2}{4w^2}\left\{e^{\frac{2wx}{t_0}}-2+e^{\frac{-2wx}{t_0}}\right\} \quad . \quad (27a)$$

Subtracting (27*a*) from (26*a*), we have

$$y_0^2-S^2=\frac{t_0^2}{w^2}$$

$$S=\sqrt{y_0^2-\frac{t_0^2}{w^2}} \quad . \quad . \quad . \quad (28)$$

Equation (28) gives us the length of arc when the running weight of the rope, and the ratio $\frac{t_0}{w}$, are known. The weight of the rope is always known in any given case.

To find the value of $\frac{t_0}{w}$, we proceed as follows:

Let Δ =total deflection or greatest ordinate of the curve.

S=span between supports.

Then, for the lowest point, the ordinate is $y_0 = \Delta + \frac{t_0}{w}$; and the abscissa $x = \frac{1}{2}$S. Substituting these values in equation (26) and reducing, we get

$$\frac{t_0}{w} = \frac{2\,\Delta}{e^{\frac{wS}{2t_0}} + e^{\frac{-wS}{2t_0}} - 2} \quad . \quad . \quad . \quad (29)$$

The equation just found is not susceptible of a direct solution; so that it becomes necessary to find the value of $\frac{t_0}{w}$ by a method of approximation. This will be done in the next section (VI).

Let L=total length of rope between supports; then from equation (28),

$$L = 2\sqrt{\left(\Delta + \frac{t_0}{w}\right)^2 - \frac{t_0^2}{w^2}} = 2\sqrt{\Delta^2 + \frac{2\,\Delta\, t_0}{w}} \quad (30)$$

To find the tension at any point, we know that from the parallelogram of forces

$$t'^2 = \left(t'\frac{dy}{ds}\right)^2 + \left(t'\frac{dx}{ds}\right)^2.$$

We substitute in this equation the values obtained from equation (20), and get

$$t'^2 = w^2s^2 + t_0^2 = w^2\left(y_0^2 - \frac{t_0^2}{w^2}\right) + t_0^2 = w^2y_0^2$$

$$t' = wy_0 \quad . \quad . \quad . \quad . \quad . \quad (31)$$

The tension t' is a maximum at the highest points. The ordinates for these points being $\Delta + \frac{t_0}{w}$, we have

$$t' = w\left(\Delta + \frac{t_0}{w}\right) = w\,\Delta + t_0 \quad . \quad . \quad (32)$$

The vertical component of the tension at the highest point is, of course,

$$ws = w\sqrt{y_0^2 - \frac{t_0^2}{w^2}} = \sqrt{w^2y_0^2 - t_0^2} \quad . \quad (33)$$

The tangent of the angle α, which the curve, at the highest point, makes with the axis of X, is $\tan \alpha = \frac{ws}{t_0} = \frac{wL}{2t_0} = \frac{w}{t_0}$

$$\left(\Delta^2 + \frac{2\,\Delta\, t_0}{w}\right)^{\frac{1}{2}} = \left(\frac{w^2\Delta^2}{t_0^2} + \frac{2w\,\Delta}{t_0}\right)^{\frac{1}{2}} \ldots (34)$$

We have now developed all the necessary equations of the catenary; but before applying them, a few remarks on the peculiarities of the curve, as shown by its equations, may not be out of place.

Equation (26) shows that the catenary rises symmetrically on both sides of the axis of Y, and becomes parallel to the same only at an infinite distance.

The angle α increases with the ordinate y; when y becomes infinite, $\alpha = 90°$; when $y = o$, $\alpha = o$.

The line CC, $\left(=\frac{t_0}{w}\right)$ is called the parameter of the curve; and the line BB., last used as the axis of abscissas, is called the directrix.

The value of the ratio $\frac{t_0}{w}$ varies between zero and infinity, $\frac{t_0}{w} = o$ when $\Delta = \infty$; for in this case the two exponents in equation (26) also become zero; $\frac{t_0}{w} = \infty$, when $\Delta = o$, because the two exponents there each equal unity. The value of $\frac{t_0}{w}$ is always very large, when Δ is small, as it always is in transmitting power by wire rope.

As will be seen from equations (31) and (32), the tension in the rope is directly proportional to the weight of the latter. The tension reaches its maximum at A and B, and has its minimum at C, where $t' = t_0$.

When Δ is small, there is very little difference between t_0 and t'; and as $\frac{t_0}{w}$ is always very large, the results obtained from equations (29) and (31) will not differ greatly.

The tension $t' = t_0 = \infty$, when $\Delta = o$; this shows the impossibility of stretching a rope so as to be perfectly horizontal; because even when it is hauled as taut as may be, there must always be a finite value of Δ existing.

Section VI.

APPROXIMATE SOLUTION OF CATENARY.

In practically applying the preceding equations of the catenary, we meet with considerable difficulty, which is owing to the fact that the parameter $\frac{t_0}{w}$ can only be obtained from a transcendental equation.

But in such work as forms the subject of this thesis, we can pursue a frequently-used method of approximation, which is abundantly accurate for all our purposes. The exact equations of the catenary, as we have deduced them, are of course applicable; but, as we have left the stiffness of the rope out of consideration, and assumed it to be "perfectly flexible," the shape of the curve is not expressed with mathematical exactitude by even these equations. For this reason alone, it might be permissible to use approximate formulæ; but we have a still greater right to use them, because the deflection Δ is always a very small fraction of the span S, and, therefore, the parameter $\frac{t_0}{w}$ is always very large.

Consequently, in equation (29), the exponent $\frac{wS}{2t_0}$ is a small fraction; and we can, without committing any great error, express its value by the series

$$e^{\frac{wS}{2t_0}} = 1 + \frac{wS}{2t_0} + \frac{w^2S^2}{2\times 4t_0} + \frac{w^3S^3}{2\times 3\times 8t_0^3} +$$

$$e^{-\frac{wS}{2t_0}} = 1 - \frac{wS}{2t_0} + \frac{w^2S^2}{2\times 4t_0} - \frac{w^3S^3}{2\times 3\times 8t_0}{}^3 +$$

Taking the first four terms of these series, and substituting them in equation (29), we get

$$\frac{t_0}{w} = \frac{2\Delta}{2 + \frac{w^2S^2}{4t_0^2} - 2} = \frac{2\Delta}{\frac{w^2S^2}{4t_0^2}} = \frac{S^2}{8\Delta} \quad . \quad (35)$$

Substituting the same terms of a similar series in equation (26), we get

$$y_0 = \frac{t_0}{2w}\left(2 + \frac{w^2x^2}{2t_0^2}\right) = \frac{t_0}{w} + \frac{wx^2}{4t_0}$$

$$y_0 - \frac{t_0}{w} = \frac{wx^2}{4t_0}$$

$$y_0 - \frac{S^2}{8\Delta} = \frac{wx^2}{4t_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

This is the equation of a parabola having a parameter of $\frac{S^2}{4\Delta}$; so that our method of approximation has led us to consider the curve as a parabola.

Substituting the value $\frac{t_0}{w} = \frac{S^2}{8\Delta}$ in equation (30), we get for the length of the curve between supports

$$L = 2\sqrt{\Delta^2 + \frac{2\Delta S^2}{8\Delta}} = 2\sqrt{\Delta^2 + \frac{S^2}{4}} \quad . \quad (37)$$

By reference to the figure, it will be seen that this is equivalent to assuming that the length of the curve is equal to twice the length of the chord of half the curve. All the formulæ previously found now become, by the proper substitutions

$$t' = w\left(\Delta + \frac{S^2}{8\Delta}\right) \quad . \quad . \quad . \quad . \quad (38)$$

$$t_0 = \frac{wS^2}{8\Delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

$$t'\frac{dy}{dx} = w\left(\Delta^2 + \frac{S^2}{4}\right)^{\frac{1}{2}} \quad . \quad . \quad . \quad (40)$$

$$\tan.\ \alpha = \frac{8\Delta}{S^2}\left(\Delta^2 + \frac{S^2}{4}\right)^{\frac{1}{2}} . \quad . \quad . \quad (41)$$

By means of these formulæ, it becomes an easy matter to investigate the various problems which present themselves.

Section VII.

DEFLECTION OF THE ROPE.

In order that the rope may be subjected to a proper tension, the deflection or sag must be of a certain magnitude while the rope is at rest; we must also know the sag of the rope while in motion, in order to estimate the necessary elevation of the wheels. There are therefore three deflections which we must determine: 1st, that of the driving side while in motion; 2nd, that of the following side wheel in motion; 3rd, that of both sides when the rope is at rest. Let the deflection at rest be called Δ_0. When we start one of wheels, the driving side of the rope rises and the following side is depressed, until the difference of their tensions is equal to the force to be transmitted, when the driven wheel will begin to move; in this condition we will call the deflection of the driving side $\triangle_1$ and that of the following side $\triangle_2$.

We must know the deflection at rest, $\triangle_0$, in order to determine the proper length of rope; so that when it is put on and spliced, we may feel certain, that there will be neither any slipping during the motion, nor any serious strain on the rope itself. The deflections $\triangle_1$ and $\triangle_2$, as before stated, must be known, in order to determine in advance, what position the ropes will take while in motion, how near they will approach the ground or other obstructions, and how many, if any, carrying sheaves are required.

By solving equation (38) for $\triangle$, we get for the value of the deflection

$$\triangle = \frac{t'}{2w} - \sqrt{\left(\frac{t'}{2w}\right)^2 - \frac{S^2}{8}} \quad . \quad . \quad (42)$$

Now, we have seen in Section IV, that if the force at the circumference of the wheel is P, then to find the deflection $\triangle_1$ of the driving side, $t' = 2\,P$. To find the deflection $\triangle_2$ of the following side, $t' = P$. Lastly, to find the deflections $\triangle_0$ of both sides while at rest $t' = \frac{3}{4}P$.

In applying equation (42) and all other equations containing t', it is to be borne in mind that t' is not the tension per square inch, but is the whole tension on the rope.

From this equation, it is evident that the tension has a great influence on the deflection of the rope. This is best shown by an example. Suppose that, with a span of 400 feet, we are using a $\frac{11}{16}$ inch rope working under a tension of 3,000 pounds. By making the proper substitutions in equation (42) we get

$$\triangle = \frac{3000}{1.20} - \sqrt{\left(\frac{3000}{1.20}\right)^2 - \frac{(400)^2}{8}} = 2 \text{ feet.}$$

Now if we had the same rope working under a tension of only 2,400 pounds, the deflection would be

$$\triangle = \frac{2400}{1.20} - \sqrt{\left(\frac{2400}{1.20}\right)^2 - \frac{(400)^2}{8}} = 5 \text{ feet.}$$

Thus, a difference in tension of only 600 pounds, causes a difference in deflection of three feet.

In both these cases, the rope will work equally well, if the size of the wheel has been properly selected; but in most cases, it is not a matter of indifference whether the rope has a deflection of two feet or of five feet.

The smaller deflection is usually to be preferred, as it requires a less elevation for the wheels. On the other hand, with a very short span the greater deflection is generally preferable.

It is, therefore, evident that we cannot decide on any definite tension to be used in all cases, but that we must select it for every different case, using a greater tension as we want a less deflection, and *vice versa*.

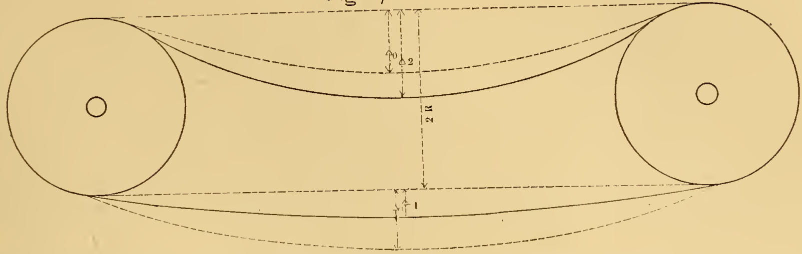
But in order that the rope may work equally well in any case, we must, as previously explained, keep the *sum* of the various tensions constant, *i. e.*, equal to the ultimate strength of the rope divided by the factor of safety. By a proper adjustment of the tension, we can, in nearly all cases, bring the deflection to any desired amount; but there is still another way to accomplish this end, as follows:

Generally, we are not compelled to make the upper side of the driving rope act as the driving side, but we can often use the lower side for this purpose. In that case the greater deflection of the lower side takes place while the rope is at rest (See Fig. 17). When in motion, the lower side rises above this position, and the upper side sinks, thus enabling us to avoid obstructions, which, by the other way would have to be removed. Of course this expedient cannot always be employed, as the upper side of the rope must not be allowed to sink so far as to pass below or even to touch the lower side. If this occurs, the rope begins to sway and jerk in a serious manner, wearing out very rapidly.

The shortest distance between the ropes is $2\,R - (\triangle_1 - \triangle_0) - (\triangle_0 - \triangle_2) = 2\,R - (\triangle_1 \triangle_2)$. We must, therefore, always be careful, in using this plan, to see that $2\,R > \triangle_1 - \triangle_2$. This result may often be obtained by a judicious selection of the tension, and of the diameter of wheel.

By the application of the equations given in this and the preceding sections, we may solve all the problems which present themselves in designing a wire-rope transmission. The following table which is taken from Mr. W. A. Roebling's pamphlet, previously referred to, will be

Fig 17



found of great value in designing, giving as it does, the most suitable proportion for general use. Its use is self-evident ; and it need only be remarked, that where there is a choice between a small wheel with fast speed, and a larger wheel with slower speed, it is usually preferable to take the larger wheel.

TABLE OF TRANSMISSION OF POWER BY WIRE-ROPES.

Diameter of Wheel in Feet.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.	Diameter of Wheel in Feet.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.
4	80	23	3/8	3.3	11	80	19	5/8 11/16	64.9
4	100	23	3/8	4.1			18		75.5
4	120	23	3/8	5.	11	100	19	5/8 11/16	81.1
4	140	23	3/8	5.8			18		94.4
5	80	22	7/16	6.9	11	120	19	5/8 11/16	97.3
5	100	22	7/16	8.6			18		113.3
5	120	22	7/16	10.3	11	140	19	5/8 11/16	113.6
5	140	22	7/16	12.1			18		132.1
6	80	21	15/32	10.7	12	80	18	11/16 3/4	93.4
6	100	21	15/32	13.4			17		99.3
6	120	21	15/32	16.1	12	100	18	11/16 3/4	116.7
6	140	21	15/32	18.7			17		124.1
7	80	20	1/2	16.9	12	120	18	11/16 3/4	140.1
7	100	20	1/2	21.1			17		148.9
7	120	20	1/2	25.3	12	140	18	11/16 3/4	163.5
7	140	20	1/2	29.6			17		173.7
8	80	19	5/8	22.	13	80	18	11/16 3/4	112.
8	100	19	5/8	27.5			17		122.6
8	120	19	5/8	33.	13	100	18	11/16 3/4	140.
8	140	19	5/8	38.5			17		153.1
9	80	20		40.	13	120	18	11/16 3/4	168.
		19	1/2 5/8	41.5			17		183.9
9	100	20		50.	14	80	17	3/4 7/8	148.
		19	1/2 5/8	51.9			16		141.
9	120	20		60.	14	100	17	3/4 7/8	185.
		19	1/2 5/8	62.2			16		176.
9	140	20		70.	14	120	17	3/4 7/8	222.
		19	1/2 5/8	72.6			16		211.
10	80	19		55.	15	80	17	3/4 7/8	217.
		18	5/8 11/16	58.4			16		217.
10	100	19		68.7	15	100	17	3/4 7/8	259.
		18	5/8 11/16	73.			16		259.
10	120	19		82.5	15	120	17	3/4 7/8	300.
		18	5/8 11/16	87.6			16		300.
10	140	19		96.2					
		18	5/8 11/16	102.2					

SECTION VIII.

LIMITS OF SPAN.

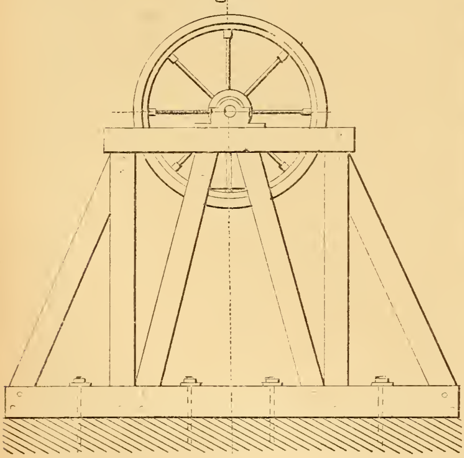
It becomes interesting to know between what limits the span may vary, without giving impracticable results.

The least practicable span is that in which the deflection of the rope becomes so small, that the latter cannot be hung freely on the driving wheels, so that special tightening devices must be used. As such may be mentioned tightening sheaves and moveable pillow-blocks. Of course it cannot be claimed that such devices make the transmission too complicated, but this merely changes the investigation for the lower limit of the span into one for the limit at which such special devices become necessary. To find the minimum value of the span we proceed as follows: From equation (38) we get an expression for the span in terms of t', w and Δ.

$$S = \sqrt{8\,\Delta\left(\frac{t'}{w} - \Delta\right)} \quad . \; . \; . \; (43)$$

By placing the minimum allowable values of Δ and $\frac{t'}{w}$ in this equation, we will get an expression for the smallest value of S. We will therefore assume that the deflection shall never be less than 8 inches $= \frac{2}{3}$ foot, and that the ratio $\frac{t'}{w}$ shall never go below 500. Introducing these values we get $S = \sqrt{8 \times \frac{2}{3}\,(500 - \frac{2}{3})} = 51.6$ feet. We thus see that the limit is very low, allowing us to use a free transmission for so short a distance as 51 feet. Below this, shafting will usually be found preferable and less troublesome.

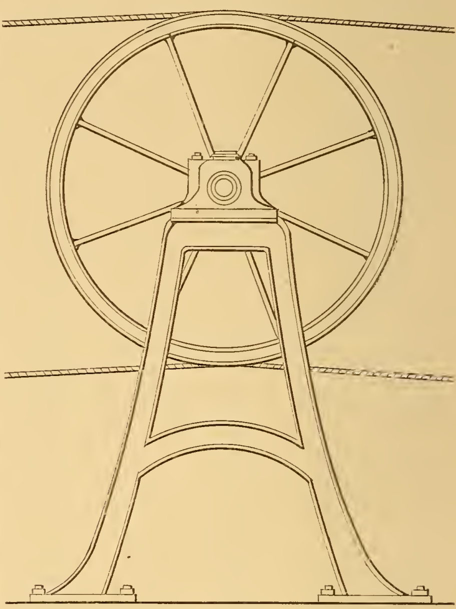
Fig. 18



When the distance of transmission materially exceeds three or four hundred feet, or when there is not sufficient height available for the sag of the rope, the latter must be supported at intermediate points by *carrying sheaves*. Sometimes it is sufficient to support only the lower following side of the rope, and generally, whatever the number of sheaves, the driving side is supported at one less point than the following side. The same number of sheaves may, however, be used, placing one over the other. The sheaves must never be placed side by side, as has been sometimes done to the great detriment of the transmission. To save still more room, we may, where practicable, make the lower rope the driving side, as previously explained.

The manner of arranging carrying sheaves and intermediate stations is shown in Figures 18–29 inclusive. The

Fig. 19



sheaves supporting the driving side of the rope must in all cases be of equal diameter with the driving wheels; and this for the same reason that the latter are usually made of so large a diameter. For whether the rope laps half way round on the driving wheels, or only quarter way round on the carrying sheaves, makes no difference; the tension due to bending is the same in both cases. With the following side, however, a somewhat smaller wheel may be used, owing to the fact there is less strain on this side, and it is therefore better able to stand the additional tension due to bending.

The system of carrying sheaves may generally be replaced by that of intermediate stations. When this is used, we have at each station, instead of two car-

Fig. 20

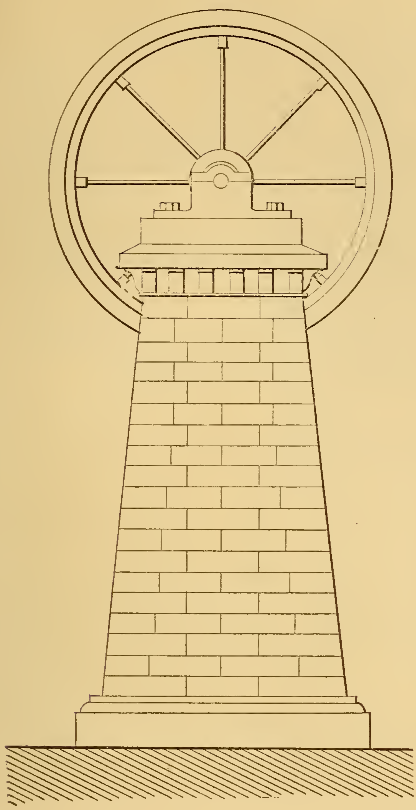
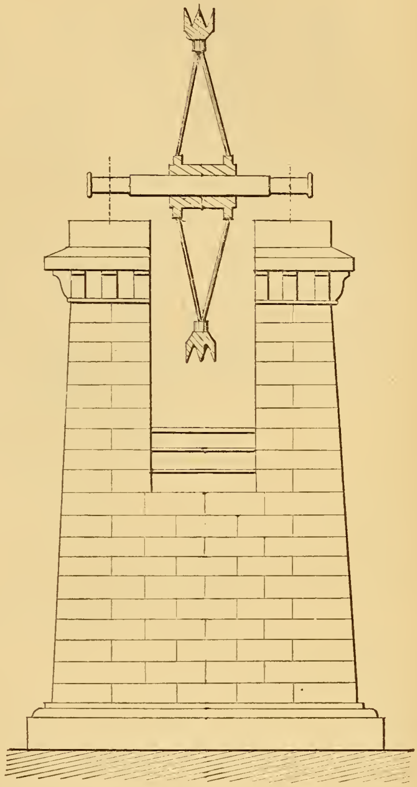


Fig. 21



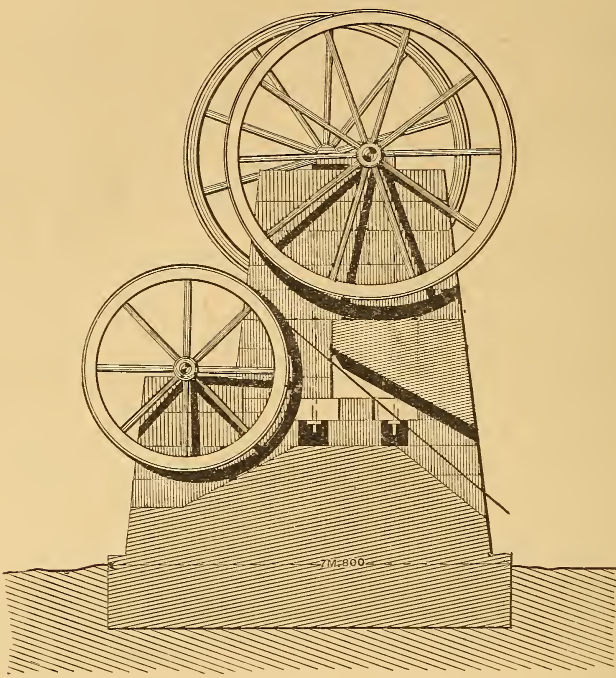
rying sheaves, one double grooved wheel. The rope, instead of running the whole length of the transmission, runs only from one station to the other. It is advisable to make the stations equidistant, so that a rope may be kept on hand, ready spliced, to put on the wheels of any span, should its rope give out. This method is greatly to be preferred where there is sometimes a jerking motion to the rope, as it prevents the rope from transmitting any sudden movements of this kind.

The supports for the stations are various. They range in dimensions and style from the simple wooden frame shown in Fig. 18, and the iron one of Fig. 19, to the more ornamental form of masonry (Figs. 20 and 21), and then to such immense masses of masonry as are shown in Figures 22–29. In Europe, the supports are usually built of masonry, while in this, wood is chiefly used, being bolted to a masonry foundation below the reach of frost. (In connection with Figures 20 and 21, I may say that the wheel there shown is one that is just coming into use. It consists of a cast iron hub and a rim, which are united by eight tension rods.) When a wooden frame is made to support the wheel, it must be firmly braced side-ways, to keep the wheel in the proper plane, but end-bracing is not required, as there is no tendency to push it in either direction.

To find the pressure on the bearings of one of the double-grooved wheels, the simplest method is by construction. Make A B= and || T, B C,= and || T., C D= and || t, D E= and || t_1, E F vertical and = the weight of the pulley and shaft, then the line connecting A and E is the intensity and direction of the resulting pressure. (See Figures 30 and 31.) When the rope is put on the wheels, it is best to use an arrangement similar to that shown in Figures 32 and 33. It is bolted to the rim of the wheel as shown.

If it is required to change the direction of the rope at some station, it can

Fig. 22



be done by the interpolation of horizontal sheaves, or by connecting the vertical driving wheels by bevel-gear. The latter is more usually employed. (See Figures 34 and 35.)

Fig. 23

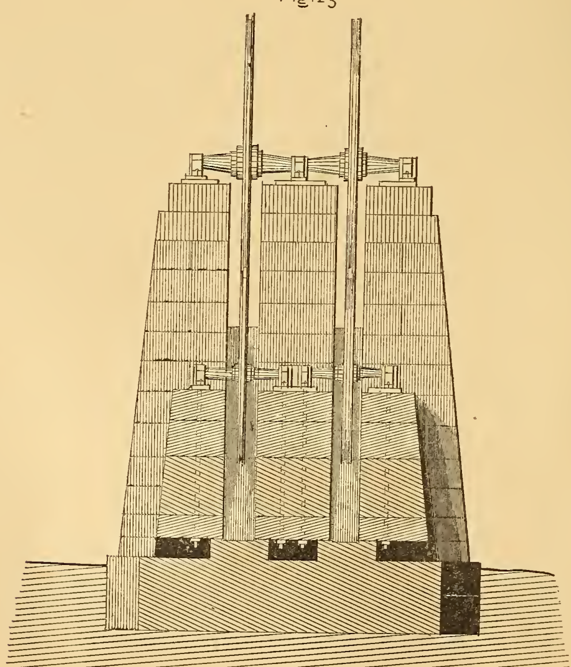


Fig. 24

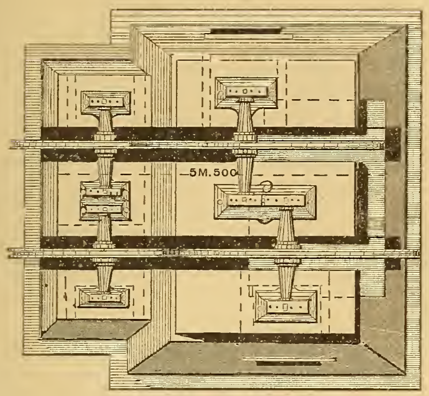
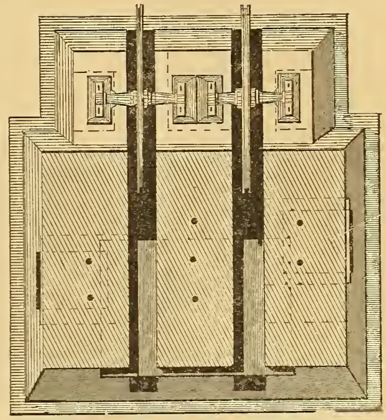


Fig. 25



Carrying Sheaves (3,150 Horse-Power).
Compagnie Génerales de Bellegarde.

SECTION IX.

SPECIAL CASES.

It sometimes happens, that the two wheels are not at the same height, as has been hitherto supposed, but that one is at a higher level than the other. This frequently happens where it is desired to use the power of waterfalls in a ravine, or in conducting power up or down the side of a hill. The rope then takes a position similar to that shown in Fig. 36.

If the difference in height is slight, we can make use of the formulæ already found, without any serious error. But if it is great, we must take a different way, for in this case the tensions at the points of support are not the same, the lower one having a less tension than the one above. This somewhat complicates the problem, causing us to proceed as follows: We first make all the calculations for the lower wheel with the deflection $\triangle_1$ and the span $2S_1$; we then find the tension in the rope at the upper wheel, and proportion the diameter of the latter according to rules previously given, so that the total tension shall not exceed the ultimate strength divided by the factor of safety. To do this we must first determine S_1; this can easily be done from the property of the parabola that

$$S_1 = S \frac{\sqrt{\triangle_1}}{\sqrt{\triangle_1} + \sqrt{\triangle_2}}.$$

when S = horizontal distance between the points of support.

The quickest and most usually employed method of getting the value of S_1 is the following. An accurate scale-drawing is made of the plan in which the rope is to be placed.

This drawing is set vertically, and a fine chain is fastened or held with its two ends at the points of support, until a proper deflection is obtained. It then becomes a matter of ease to measure S_1 and S_2, and to make all the necessary calculations. We can, in this way, try differne deflections and observe their suitability to the design, but must always bear in mind, whether we are getting the deflection of the driving or of the following side or that of both sides at rest. This method, though not giving as great accuracy as the solution of the above equation, is nevertheless largely used in practice, owing to its great convenience. It may be used when the pulleys are on the same level, showing between what limits we can work.

Another peculiar case is when the rope rises nearly in a vertical direction. This is the limiting case of the inclined transmission. The rope produces no tension whatever on the lower wheel, while at the upper wheel the tension is only equal to the weight of the rope. Even this last tension is such a small quantity as to be left entirely out of consideration, and we are consequently obliged to use some device for producing the requisite tension. Figures 37, 38 and 39 show various ways of accomplishing this object by means of tightening sheaves.

Fig.26

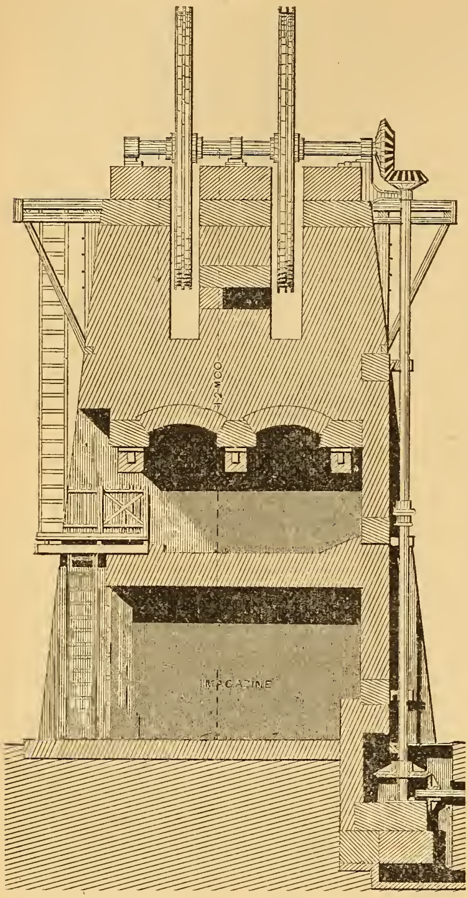


Fig.27

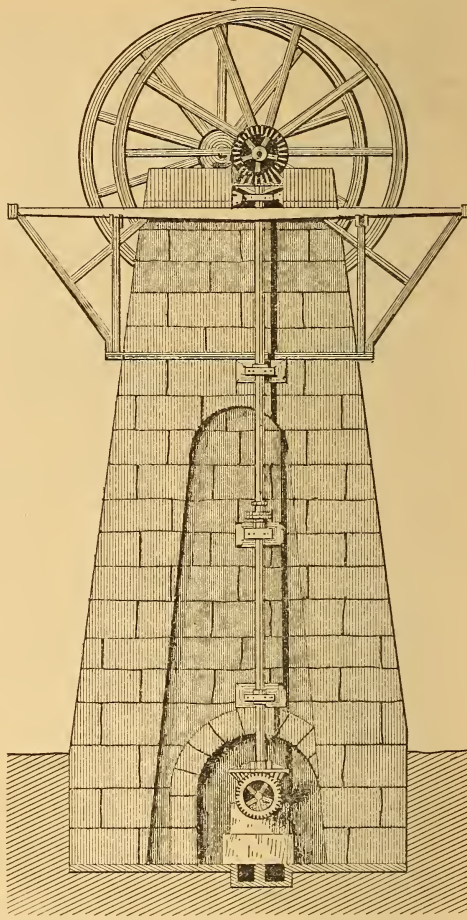


Fig.28

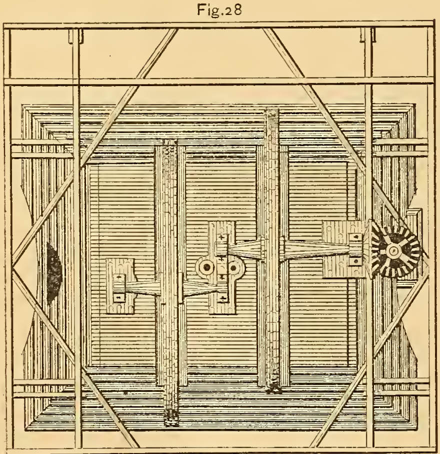
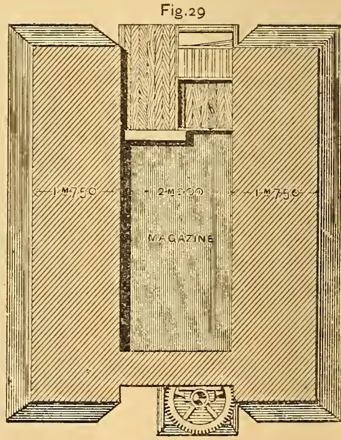


Fig.29



Intermediate Station (3,150 Horse-Power).
Compagnie Générales de Bellegarde.
(See *Engineer*, vol. 37, 1834,)

In Fig. 38, as the rope passes around the wheel twice, the same must be provided with two grooves. Instead of these tightening sheaves, we may, when practicable, put up two carrying sheaves as shown in Fig. 39, so as to have horizontal stretch enough to obtain the tension necessary.

See March number for the remaining cuts.

ENGINEERING WORKS IN INDIA.

From "The Builder."

One of the features which have most struck the imagination of the English public, and, which have, perhaps, increased the disinclination at first naturally existing for the investment of capital in a distant and strange country, is the magnitude of the public works attempted and carried out in India. No doubt, individual works of great magnitude may be cited. The annicut across the Sone is two and a-half miles long in an unbroken line. The two main canals starting from this point are each 150 yards broad, and ten feet deep. The bund of the Veranum tank in South Arcot is twelve miles long, and about twenty ft. high. The tank itself is $2\frac{1}{4}$ miles wide in the widest part, and it will contain about one hundred million cubic yards of water. The highest bund which Sir Arthur Cotton has seen was fifty-four feet high, although he believes that there is a tank with a depth of sixty feet of water.

Noble as these works unquestionably are, it is rather in distribution than in gross magnitude of work that the labors of the engineer in India differ from those of his professional brother in England. We can point to no railway embankment of twelve miles long, but it would be only a very small railway that did not contain twelve miles of embankment distributed in various portions of its course. In the works at the head of river deltas, as in the case of the Cauvery, or in those for collecting water in the hills, as in the instance of the Veranum tank, a vast amount of work, intended to affect many hundred miles of country, is concentrated. The physical nature of the country demands this kind of work. But the details are as simple, and the cost is not much more, than that of the same quantity of work distributed over a larger area of country. Nor can either the cost or the magnitude of these great embankments and dams compare, in a disadvantageous manner, with that of such familiar undertakings as the bridging the Menai Straits, or the tunneling under the streets of London.

The simplicity with which works of permanent stability have long been constructed in India is a feature of their engineering to which we shall do well to pay attention. Extending over a great range of country, and formed out of every kink of material, the bunds are made without any such contrivance as a "puddle trench," which Sir Arthur Cotton regards as essentially mischievous, tending to lead to cracks in the mass of the bank. The great point is to have the embankments made of homogeneous material, so as to allow them to settle equally. Great watchfulness is also requisite, in the wet season, to prevent any overflow, except through the properly arranged sluices. The bursts of rain in the Carnatic are tremendous. As much as five inches of rainfall in a single night is not unfrequent, and Sir A. Cotton has known as much as twelve inches of rain to fall in that time. The smallest rill that is allowed to trickle over the edge of an earthen bank wears itself a passage, and becomes a destructive torrent with extreme rapidity. On one occasion the water in the Veranum tank is said to have overflowed the whole twelve miles of the bund, and to have breached it in thirteen places. On another occasion the engineer in charge of a bund, finding the water rising with more rapidity than he was able to meet by the supply of earth, made a wall of the bodies of his laborers, causing them to lie down close to one another on the top of the threatened part of the dam, and thus keeping back the two inches or three inches of water, which, if unchecked, would soon have wrecked the whole bund, and ruined a wide district, until their places could be supplied by baskets full of earth. It was an original expedient, but it saved the district. What the laborers said about it we have not heard.

The districts of India which are naturally fitted for such works are full of noble tanks, of native construction, some of which are of venerable antiquity. Till within the last thirty years very little was done to keep these important works in repair. In 1827 the Veranum tank was in such utter disrepair that the people were almost in a state of rebellion from want of water. A report that the sum of £3,500 ought to be laid out on it was made in that year; but by 1833 no steps had been taken to carry out the order for the work, and the people were in such a state of discontent that it was feared that it would be necessary to send troops into the district. A large number of tanks have now been put in good order by the Government. In Mysore the condition of these works, under the charge of Commissioners who have a considerable degree of power, is said to be excellent. In Madras there is great room for improvement. In Bombay two new and capacious tanks have been formed by shutting up valleys, one by a masonry bund, the other by an embankment of earth. Each will contain about 140 million cubic yards of water when the waste-weir is closed. But as, during the four months of the monsoon, a tank supplies water to the dependent canals at the same time that it is filling, the water which it preserves from being wasted is more than its actual contents when full. The tanks in question may thus convert to useful purpose as much as 200 million cubic yards of water a piece per annum. The loss by evaporation during the year is estimated at seventy-two inches over the surface of the water area, which will amount, in the cases in question, to about six per cent. of the whole supply afforded by the tanks.

The cost of the tank with the masonry bund, which is near Poona, is not at present accessible. The other, which is near Sholapoor, cost £90,000; of which some £20,000 were spent on the canals for distribution. The capital laid out was thus about £500 per million cubic yards of the contents of the tank, or £370 per million cubic yards of the water actually utilized in a year by its agency.

Near Nagpoor is a site where it would be quite practicable to form a tank that would contain 2,000 millions of cubic yards of water. Such an inland sea would feed the stream of the Godavery for 200 days in the year with an average supply of 400,000 cubic yards of water, which is double the flow to which the river is now reduced in the dry season, thus facilitating the navigation of 500 miles of canal, besides the ultimate application of the water to the irrigation of the crops. The cost of such a work, which Sir A. Cotton estimates at £400,000 would not amount to more than £800 per mile of navigation, or, at seven per cent. to about £70 per mile per annum for supply of water to the canals.

The great special works of the annicuts or dams at the head of river deltas, and of the tanks, or mountain reservoirs, for storing the copious rainfall of the highland districts, are, as we have seen, special features of India. In that portion of the system which lies between the tank and the annicut, we have occasion for works of a kind with which English and Dutch engineers have long been familiar; not that the peculiarities of the Indian climate do not impart a special character to Indian canal work. An Englishman would be apt, on looking at the map of India, to conclude that, in order to conduct an enormous amount of inland navigation, it would only be necessary to put boats on the great rivers. Had this been the case, the natives would not have left it to us to show them the way to do so. In point of fact, while greatly respecting the military power of England, they consider us, as engineers, as little better than savages,—anyway, inferior to some of the native rajahs who constructed the great works of past years. Nor can it be denied that in what, after all, is one of the best tests of the skill of the engineer, namely the production of a given effect with the least expenditure of power, and with the simplest machinery, the Indians have many centuries ago arrived at a *ne plus ultra.* Long before the science of the French engineers had arrived at the fact that the mode in which human labor can be most efficiently exerted is by man's raising his own weight, the Indians had watered their rice-field on that very principle. We have seen, five and twenty years since, in France, elaborate contrivances for raising earth, at which an English navvy would laugh, but by means of which human labor became cheaper than horse labor. An incline plane was constructed at an angle of between 45° and 60°, and two platforms were connected by wheels, chains, and pulleys, in such a manner that as one ran up the incline the other ran down. On to the platform which happened to be at the bottom the barrow-man wheeled a barrowful of earth, and left it there in the barrow. A couple of laborers quietly made their way up a sort of half-ladder, half-staircase laid up the slope, walked on to the upper platform, which descended by their weight, and thus raised the barrow of earth to the upper level. The daily work of a certain number of workmen thus consisted in walking up the slope and riding down it. It was an easy occupation, but the very ease depended on the fact that the muscular energy necessary to raise so many tons of earth so many feet in height was thus most efficiently exerted. A man can work in this way at the best advantage, just as a horse can do five times the amount of haulage at his natural pace of two miles and a half an hour that he can do at the driven pace of ten miles an hour. In England the work would either have been done by relays of barrowmen, each wheeling the barrow for a run, or by the aid of a horse, pulling the barrow, and in some cases the man who guided it, up a steep incline. The French mode, strange as it looked to a muscular Englishman, was really the cheapest. It involved, of course, some preliminary outlay in machinery. But the Hindoo lays a long plank, notched, to prevent slipping, over the fork of a post which he drives into the ground near a supply of water. That is all his machine, and very often the post takes root, and grows into a tree that shelters the workmen. The water vessel, and the bamboo which attaches it to one end of the plank, the workmen take home at night, to avoid theft. The day's work then consists in something like the English boy's game of see-saw, the man walks along the plank backwards and forwards. As he approaches the tree, the water-vessel dips into the water. As he walks to the other end of the plank, the vessel is raised. The Madras engineers have made careful theories of the statistics of the employment of human power. Sir Arthur Çotton says that the cost of water raised by this contrivance, which is called a picottah, is about the same as that raised by bullocks, being about £1 per 3,000 cubic yards. The great points to admire are the extreme simplicity of the machinery and the exertion of the minimum labor on the part of the workmen.

It is thus tolerably clear that any one who approaches the question of Indian irrigation and water-carriage, with the lofty idea that we have but to carry the science of our own highly-civilized country to the aid of a barbarous people, and that wealth and ease will follow our footsteps, totally misconceives the nature of the problem to be solved. In very much, of course, the progress of manufacturing industry made by us within the present century, gives us a great advantage over the Oriental who has never seen a steam-engine. But the rapidity with which the Hindoo, still more the Chinese, or the Japanese, will rise, by his great imitative powers, to the level of the European workman, is one of those facts which it would be well for this country if the English workman fully realized. In the Mint works of Madras and Calcutta, Colonel Smith trained native workmen so closely to emulate his English workmen, that he obtained from the former, at the price of an anna, that for which he had to pay the latter a rupee. This is an extreme case, and the craft of the moneyer is one in which the Hindoo might, perhaps, have been expected to excel. But, as a general rule, what India demands at our hands, is rather Governmental facilitation of remunerative works than anything else. Even capital, our great reliance, is not so much the need of India, as confidence. There is abundance of native capital that would be forthcoming for works such as those which India requires, if only the wealthy natives were convinced of the hearty good wishes and sanction of the Government. To those of our readers who have never been out of England, this assertion may seem incredible ; but those who know the East, or even who know many parts of the South of Europe, are well aware of the slavish terror with which the mass of the people regard even the smallest official. Experience is ample and conclusive to the effect that the natives will hang back from supporting an object which they sincerely desire, if any jealousy or stupidity in the great hierarchy of officials gives them the suspicion that the Government does not really wish that object to be carried out. Convince them of that, and do so by giving that information and that admistrative aid of which the Goverment has the means of disposing, and the degree of local support that will be forthcoming for well-considered schemes, will be quite enough to satisfy the friends of India.

In the case of river navigation, the impulse of the central power is required, from the fact that widely-distant districts of country have a real solidarity of interest which only the central power can comprehend. Thus in the case of the proposed storing of the water of the Godavery this very cause of dispute has arisen. The new tank would be in one district; the main utility of its contents would be in another. But the former district intimates that it would consider the water stored in its valleys as its own, and would consult its own interest in its distribution, heedless of those of the lower river basin. Meantime the Cauvery is comparatively useless as a highway during the very season in which the carrying trade is naturally most active. A wise and comprehensive policy, collecting all the facts of the case, and facilitating administrative action that should most tend to the common good, is thus the prime need of India as regards public works.

The importance of canal development in India is one that cannot be measured in money. It is, indeed, possible to estimate the loss to the State, in mere annual revenue, that is caused by a great famine. But such a calculation, to say nothing of its quiet cynicism, is very far from representing the actual loss incurred by the decimation of a great province. In 1874, in consequence of a famine due to the want of water, about 4,000,000 people were fed by the Government in Bengal for some four months. They must, in that time, have consumed 350,000 tons of grain. This, not at the famine, but at the ordinary price of rice, must have cost £2,100,000. The grain required might have been produced on 700,000 acres of land, by the application of 6,000 cubic yards of water per acre, or 4,200 million cubic yards. The value of this water would thus have been £1 for 650 cubic yards, or more than a hundred-fold the cost of its storing and distribution. In Orissa, in 1866, there was a famine. The idea that it was within the power and the duty of Government to save the lives of the people had not taken root. The official papers state that a million and a half died. The loss of revenue to the Government, at 2½ rupees per head per annum, was £375,000 for the year. At twenty-five years' purchase, this gives a national loss to the revenue of £9,377,000. To save these lives would have required 150,000 tons of grain, costing £900,000, which it would thus have secured a tenfold profit to the Government to provide. But to have raised that quantity of rice would only have required the distribution of 1,800 million cubic yards of water. The value of this water, that is to say, its productive value, would thus have been 260 yards for a pound. Its cost, which by the *picottah* we have seen to be 3,000 cubic yards for the £1, we have found on the great irrigation works to be reduced to 70,000 cubic yards for £1. These are incredible margins between the cost of neglect and the cost of forethought; to say nothing of the vast amount of human misery entailed by what has been shown to be a preventible evil—local famine.

Not only in the production, but in the distribution of food, canals already play no small part in the production of the wealth of India. How very little now needs to be done in order to complete the service of some of the most important districts it is satisfactory to know. At the same time it is all the more urgent that the works in question should be pressed, with the least possible delay. Thus, if the 7,000 miles of canal which have been designed as easily to be constructed in connection with river navigation in India were made (being less than twice the mileage of the canals of the United Kingdom), and if they conveyed an average traffic of two millions of tons over the entire system (which is the actual traffic of the Aire and Calder), the cost, at one-tenth of a penny per ton mile (which is double that which Sir Arthur Cotton estimates), would be £6,000,000. The same amount of transport by road, at 3*d* per mile, would cost £180,000,000. By railway, at the existing rate of charges, it would be £90,000,000.

It is thus clear that the absence of water communication forms the bar to an immense internal traffic, which would not only augment the wealth of India, but would have a direct effect on the English market. Thus it has been calculated that the wheat which is at this moment selling on the Upper Mahanady at 9*d* a bushel may, on the completion of the designed lines of inland navigation, be landed in England at 2*s* 6*d* per bushel cost price. The effect of this, or of anything approaching to this, immense revolution in the corn trade would be prodigious. From twenty to thirty millions a year would be paid to our own subjects in India, instead of to the United State. A corresponding outlet would be afforded to the goods of Manchester and our great manufacturing centres. Where merchants are now anxious to obtain a reduction of 2*s* or 3*s* per ton in freight by sea to Calcutta, they overlook the fact that is within the power of the engineer to reduce the rate of transport for 1,000 or 1,500 miles in India itself from 1½*d* to one-tenth of a penny for ten miles, or by 150-fold.

The total expenditure upon the irrigation works of the North Western provinces of India, up to the end of 1874–5, has been £4,565,578 sterling (at the valuation of 10 rupees to the pound). Out of this sum £22,197 were laid out on works that have been abandoned, and £675,175 on works under construction, from which no revenue has yet been derived. The balance of £3,836,517, represents works in partial operation, although yet incomplete. These are chiefly from,—viz., the Ganges, Eastern Jumna, and Agra Canals, the Dun, Rohilcund, and Bijnour water-courses, and the Bundelkhund Lakes. Of these the canals alone have cost £3,632,051. In the second series the principal work is the lower Ganges Canal, now in the third year of its progress, on which £622,502 have been laid out. The income assessed for the first year in water rates and miscellaneous income on the partially opened canals was £295,560, to which has to be added a figure of £85,887 credited in the civil accounts as increased land revenue due to the operations of the canals. On the total revenue of £381,447 the working expenses have been £132,493, or 34·6 per cent., a ratio that no doubt will be considerably reduced by the completion of the works. As it is, however, the net revenue is enough to pay a dividend of 6·49 per cent. on the capital expended. These figures include the first year's operation of the Agra Canal, on which the expenditure has exceeded the income. Setting this aside, as a temporary feature, the profit on the works in full operation, has been 7·48 per cent. on the capital expended to the close of the year. On the Eastern Jumna Canal alone, the profit on the outlay has amounted to the high ratio of 29·17 per cent. It will therefore be seen that the latest statistics furnished by the Indian Government, are such as fully to bear out the statements of the advocates of irrigation canals.

It will be a thousand pities if facts like these are shrouded with any discredit by the personal views—not to say whims—of any of those persons to whom we have to look for information as to India. Especially we regret the attacks made on the Indian Government, and on the Indian railways. As to the latter, the wine is drawn, and we have to drink it. More than that, the majority of persons in this country will think that it has been well drawn. To construct 6,000 miles of great strategic lines at one-third the cost per mile of the English railways, and so to work them as to earn a *bona fide* 3½ per cent. on the capital, is not, in our view of the case, bad work. The fact that canals can be constructed at £1,000 or £2000 per mile does not invalidate the position of the railways. But it does give promise of abundant increase of the wealth of India, and that increase will affect the railways advantageously,—whatever be the bulk of goods and number of passengers borne by water. Far more than was the case in England forty years ago has the internal traffic of India to be created. That it will spring up with immense rapidity we do not doubt. Nor do we hesitate to repeat that the main charm by which the face of India will be furrowed by canals, roads, and irrigation works will be found to be in producing the local conviction that the Imperial Government has that development of the communications and resources of India deeply and truly at heart.

OVERCOMING STEEP GRADIENTS ON RAILWAYS.

By HENRY HANDYSIDE.

Journal of Iron and Steel Institute.

The chief object I had in view, when, in 1871, I first matured the idea of the new system, was to provide a cheap and efficient means whereby the locomotive of ordinary construction might be made available for surmounting steep inclines, and without any alteration or addition to the ordinary permanent way, or alteration in section of rails.

The subject is naturally divided into two parts; the going up, and the coming down, and I propose to describe them in that order.

There is no portion of railway engineering so arbitrary and well defined as the law of inclines.

On all ordinary locomotive lines, the steepest portion becomes "the ruling grade" for the whole line; that is to say, the ruling grade decides the weight of the locomotive, the exact load it can draw on that grade, and the weight of the rails along the whole length of that line, on which that locomotive has to run.

There is no difficulty in apportioning the steam power of any locomotive to the amount of its adhesion, and as this adhesion is solely dependent on the amount of weight which can be put upon the driving wheels of the engine, it follows that the load any engine can take up an incline must be in an exact *ratio* to the weight on the driving wheels, and the angle of the incline.

It has been ascertained by actual experiment, that the limit of adhesion between an iron tyre and iron rail, is on an incline of 1 in 6; or in other words, any locomotive, with sufficient cylinder power, and all wheels motors, will ascend an incline of 1 in 6.

Any very close approach to this limit would be of little commercial value, and the nearest which has been successfully employed, is an incline of 1 in 10, which was worked for three years on the Baltimore and Ohio Railway, the engine taking up a load as heavy as itself—this fact is recorded in Mr. Isaac's interesting paper, read before the Institute of Civil Engineers, on November 23rd, 1858.

Thus it appears evident that it is not the steam power of a locomotive that is wanting, but the adhesion between its wheels and the surface of the rails.

To supply this great want has been the object of locomotive engineers from the earliest days of the steam engine, and very numerous and varied have been the mechanical contrivances brought forward, many of them performing all requirements, but laboring under the disadvantage of additional cost to permanent way, greater weight and complication in the engine itself, and all being obliged to devote their steam power to ascending the incline at the same time with the load.

It is on this point that my system differs from all others ever used. I use any ordinary locomotive, applying thereto a winding engine and steel wire rope, or chain, and peculiarly constructed gripping struts, which also perform the duty of a most powerful brake when descending.

The engine having hauled its train to the foot of an incline, of say one in twelve, disconnects itself, but leaving the end of the wire rope fast to the train, it proceeds up the incline for any desired distance, but within the limits of the length of the rope.

The struts, having been released by the engine driver, immediately come into play, firmly grasping the heads of the rails, and thus the engine becomes at once a stationary winding-engine. By the application of steam to the winding cylinders the train is drawn up close to the engine.

If the incline is of too great a length to be surmounted in one lift, a similar pair of gripping struts are fitted to the last wagon or guard's van of the train, and as they act quite automatically, the train is firmly held in its place whenever the winding ceases.

This automatic action of the struts, when fully understood, will recommend itself for adoption in all cases where retrograde motion is to be feared on steep inclines; and even on those in this country on some of the main lines ranging from one in forty to one in sixty, and on which such disastrous results have followed from the breaking of couplings or draw bars.

In laying out a new line for my system, I prefer to keep the steep inclines straight, and with the limit of wire-rope the engine can carry. I prefer not to exceed 300 yards, each incline to be followed by a piece of level, which may be taken advantage of for curves. Thus, the ascent of the line is made by a succession of steps, and resembling in its action the working of a canal with locks.

My chief reason for keeping the inclines straight, is to dispense with cast iron guide pulleys, which are objectionable, entailing great friction and wear and tear to the rope; if, however, the nature of the ground is such that the incline and curve must be combined, then the ordinary guide-pulley may be resorted to.

When the inclines are kept straight but very few wooden rollers are sufficient, the rope bearing very lightly and only for a portion of the lift; this is due to the rope being coupled to the drawbar of the wagon and the top of the winding drum, at least three feet six inches from the level of the ground.

It is evident that by this transformation of an ordinary locomotive into a stationary winding engine, it combines and uses all the advantages to be derived from either or both.

Long experience, apart from the theory of the question, has determined the economy of the rope system, and the nearer the vertical lift is approached, the greater the economy of working—but the risk increases in equal proportion.

It is an easy matter to provide against an accident when going up, either an incline or vertical lift, but the descent has to contend with the formidable powers of gravitation and accelerated momentum.

This brings me to the second part of my subject, "the coming down."

As I have mentioned, I prefer to cut up my line into steps—keeping each steep incline of a comparatively short length. By this means I can reduce the danger to be anticipated from accelerated momentum; for, supposing the brakes to be overcome, which would never be the case until probably one-third, or one-half of a short incline had been descended, then all the speed any train could acquire sliding to the foot of the incline would soon be overcome when the train came on to the level.

We know by practice that all railway stock has an adhesion to the rails equal to one-fourth of its weight, although many engineers in this country do not think more than one-sixth ought to be relied on.

Taking even the latter as a datum for braking purposes, it is clear that any railway wagon or carriage, with proper brakes on all the wheels, could descend an incline of 1 in 12 with perfect safety, so long as a certain speed was not exceeded, but the great danger is that this speed might be exceeded, even under the charge of the most experienced brakesman, who would have no greater retarding power to apply to, and that train would "run wild."

Foreseeing that this evil must be provided for, I have so constructed my gripping strut that it acts as a brake of the most powerful nature when coming down hill.

The construction of this brake causes it to press, not only on the top of the rails, but also in as great a degree on the sides of the heads of the rails. To provide against wear, the three bearing surfaces of each shoe are made as renewable pieces of iron or brake metal, which can be removed and replaced in less than 20 minutes.

This brake will work on any section of rail, but it must be apparent that the deeper and flatter the sides of the tops of the rails are the greater will be the effect produced with the least amount of wear on the renewable faces of the brake. Some who have seen the action of this brake, having at once admitted its great retarding power, have qualified the praise by saying it could not be made generally available on our lines on account of "points and crossings."

This, at first sight, appears a most formidable objection, but, like every mechanical difficulty, it ought to be, and has been surmounted.

In the case of the application of my brake to a locomotive, Mr. Walker (of the firm of Fox, Walker, and Co., Bristol) has made a very ingenious adaptation of steam power, by which the brake is instantaneously and automatically lifted off the rail when coming close to a point or crossing.

A similar arrangement, in the case of a guard's van, can be secured by the use of compressed air, or even by ordinary mechanical appliances.

Although I can fully agree with the general opinion that, "it is desirable that brakes should work equally well over points and crossings," I still think it will be admitted that, although danger is generally to be anticipated in the immediate vicinity of points and crossings—that in nine cases out of ten, when brake power has been insufficient, the engines and trains were running on clear rails, and might have been brought to a stand before the points and crossings were reached, if the driver and guard had been in possession of some greater and reliable retarding power.

By the application of this brake to a locomotive, its retarding power is nearly trebled, an advantage of no small importance, especially when under the control of the driver, who is the sole and proper person to have full control over his engine and train.

All the retarding force which can be derived from the top surface of the rails has long been known and utilized to the utmost, as it has often been found insufficient on our ordinary lines, and as it would certainly be quite insufficient on steep inclines, I have ventured to utilize a portion of the ordinary rail which can well afford to take its share of work when required.

My great object in bringing the subject of overcoming steep gradients before your notice, is to prove that by this simple adaptation of certain well-known machines, in combination with various novel appliances, a railway system is produced which will enable the engineer to undertake the construction of mineral lines at a much lower rate than heretofore.

I do not say that the cost, mile for mile, will be less in all cases, as compared with a line laid out with ordinary grades; but it will enable the engineer to take a more direct route, and effect a large saving in actual distance or length of permanent way—generally as much as sixty per cent., and after giving him the power of taking his line in certain directions to suit the wishes of land-holders, in some cases, thus removing the chances of a strong opposition, which, in several instances, has prevented an easy access to districts, known to be rich in mineral wealth.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The last number of the Journal of this society is of double size and of proportionate value. In addition to the reports of committees and officers, it contains such summaries as are incident to the close of the fiscal year: The present number includes a full report of the addresses and subsequent discussions on the subject of technical education at the joint meeting of the Civil Engineers with the American Institute of Mining Engineers at Philadelphia, in June, last.

To American students this report, embodying the views of eminent American Engineers on the subject of education, is the most valuable treatise yet published. We hope to see it published in such form as shall place it within easy reach of all.

The annual reports all indicate a peculiarly vigorous condition of the Society.

The annual convention is to be held in New Orleans in April.

IRON AND STEEL NOTES.

Compressed Steel.—Speaking at the Iron and Steel Institute on the application of hydraulic power in forging, Sir Joseph Whitworth stated that his firm had recently completed two twin screw shafts for the *Inflexible*, 283 feet in length, seventeen inches in diameter, and cast with a nine inch hole through them. These shafts were made of compressed steel, and weighed sixty-three tons, instead of ninety-seven tons if made of iron,—a reduction permitted by the great strength of the compressed steel. He further stated that on applying the hydraulic pressure, a column of metal is reduced 1 8th in less than five minutes,—a remarkable indication of the effect of pressure in expelling air-cells. The strength of the shaft was forty tons to the square inch, and its ductility or power of extension was thirty per cent. of its length. By using compressed steel, the driving round of thirty-four tons was saved during the whole life of the engines.

Steel Rails in Germany.—Herr Funke, of Cologne, has contributed to the journal of the German Railway Union some valuable information upon the relative value of steel and other rails. Experiments, commenced in 1864, have been made with rails of different materials, but laid under similar conditions upon the Cologne and Minden line where the traffic is heavy. The rails tried were 150 fine-grained rails, 150 cemented rails, twelve of Funke and Elber's puddled steel rails, twelve of Hoesch and Sons' puddled steel rails, 149 of Hoesch and Sons' Bessemer rails, 147 of Krupp's Bessemer rails, and 150 Bessemer rails from the Hoerde Works. On the 1st of October, 1875, after eleven years' service, 115, or 76.7 per cent., of the fine-grained rails have been renewed; ninety-five, or 63.3 per cent., of the cemented iron rails; four, or one-third, both of the Funke and Elber's and the Hoesch and Sons' puddled steel rails, and of the Bessemer rails; seven, or 4.7 per cent., of the Hoesch and Sons; six, or 4 1, of the Krupp; and two, or 1.3 of the Hoerde rails; of the Bessemer rails one broke through the bolt holes, one scaled off on the head, and the other three were beaten down and flattened out at the joints, without being entirely spoiled. Pieces were cut from the ends, and then they were used again in sidings. The flattening at the joints is charged to the form of the rails, which have a pear shaped section, and could not be fastened firmly at the joints. Taking the mean of the Bessemer rails, the necessary renewals after ten years service was 3.4 per cent., against 33.3 per cent. of the pudd ed steel, 63.3 of the cemented, and 76.7 per cent. of the fine-grained rails. The average tonnage, excluding engines, over these rails was about 18,000 tons per day. The result of this trial was the adoption of Bessemer steel. Altogether the company has had, in the eight years from 1868, to 1875, 504,634 different Bessemer rails, which at the close of this period had been in use on an average two and a half years. In that time 1625 had been replaced, or 0.322 per cent. of the whole number. At the end of 1875 the iron rails had been in service on an average 6.98 years, and within that year 6¾ per cent. of them had been replaced, while in the same year only 0.2 per cent. of the Bessemer rails—in use an average of 3.8 years—had been renewed. Experience has not shown that steel rails break easier than iron ones; 0.238 per cent. of the whole number had broken down to the end of 1875. More of steel than of iron break very soon after they are laid often under the first train that runs over them. Since 1867 the company have bought 17,600 tons of iron rails and 153,000 of Bessemer rails; but since 1872 it has bought nothing but Bessemer rails.

Hot Short Steel.—A Mr. F. Valton has been for some years manager of certain ironworks in Siberia which are the property of Prince Demidoff. Bessemer plant has been recently erected at these works, and in order to test the quality of the metal made, the ordinary continental practice was pursued. A small ladleful of metal was taken from each "blow," and forged at once into a little bar, after which it was re-heated very hot, and bent over and hammered down on itself. The bar cooling down all the while, each doubling was done at a different temperature. Working in this way, Mr. Valton found that a bar which bent quite well at any temperature from a red down to a blue heat, invariably broke at the latter temperature. If the bar were cooled down still further, no fracture took place. In other words, this steel was perfectly tough, sound, and good at any temperature above or below from 360 to 400 deg. Cent.—that is to say, the temperature at which a piece of wood brought in contact with the hot metal just begins to carbonize. At first Mr. Valton and his assistants believed that they must be deceived; but the most careful research proved that there was no deception about the matter, and that the steel they made was really extremely brittle at and about a good blue heat. The natural conclusion was that this phenomenon was limited in manifestation to Prince Demidoff's Siberian steel, and that the defect was probably due to the presence of minute quantities of copper in the pig. But to settle the question Mr. Valton procured specimens which it was certain must be unlike the defective metal. These specimens consisted of Tagilsk charcoal irons, made as far back as 1770, and kept in a museum; Oural irons, both bar and sheet; mild Bessemer and Martin steels from the Terrenoire Works; Mild English steels; and, finally, English rails of good quality. All these specimens, hammered, rolled lengthwise and then across, gave precisely the same results. They were a l brittle at 360 to 400 deg. Cent. Mr. Valton naturally concluded that he had made a somewhat curious discovery; when some of the men, finding out what he was about, told him that there was nothing novel in the matter, as they had been familiar for years with the facts, and that, in working fine Russian iron under the hammer, it was necessary to stop hammering when the plate had fallen to a given temperature, guessed by the workmen by the eye. The hammering could not be renewed with safety until the metal had fallen still further in temperature. Further researches tend to show that the phenomena are only manifested by good metal, or perhaps it would be more correct to say, that they are not displayed by bad irons or steels. Mr. Valton has read a paper on the subject before a Russian learned society, in the course of which he said, "Iron and steel may, in a large number of cases, have to endure strain at a temperature analogous to that I have spoken of above. Boiler sheet, fire-arms, or badly oiled axles, may, any of them, rise to a heat over 300 deg. Cent., and the metal may then, in the most unforeseen manner, suddenly lose more or less of its power to resist strain, *i.e.*, its strength. I think there is fair ground for making a series of methodical experiments on the loss of strength on the part of iron and steel under the conditions I have pointed out. If the property noticed is a real and generally recurring one, it should be known as generally, so that all interested should be put on their guard against the possibilities of accident which may occur therefrom." It will be seen that in this case Mr. Valton's men had known for some time what he was at considerable trouble to find out.—*Engineer.*

RAILWAY NOTES.

The Beira Railway.—The Portuguese Government have sanctioned the project for the upper Beira Railway, which is to unite the existing line between Lisbon and Oporto, and thus shorten the journey from Paris to Lisbon *via* Madrid by a whole day. It will leave the Portuguese line near the Coimbra station, traverse the whole of the Mondego Valley, and terminate at the Spanish frontier, where it will join the Salamanca Railway. The construction and working of the line have already been advertised for tender, and the competition will be open for sixty days from the 22d June. The conditions, according to the *Diario do Governo*, are rather remarkable. The first step for the competitor is to deposit at the Bank of Portugal the sum of 750,000f,—£30,000—the base of the tender being the amount of the subvention per kilometer. The successful competitor will have to increase his deposit at the bank to 1,500,000fr.—£60,000—while the remaining deposits may be withdrawn. The concessionaire, whether an individual or a company, will undertake, at his own risk, the construction of the line with the expropriations, earthwork, bridges, laying the rails, stations, repair shops, &c.; he will supply, maintain and renew the locomotives, goods wagons, passenger carriages, &c.; he will, in fact, provide all the permanent way and rolling stock, as well as telegraph the whole length of the line. The railway is to be in accordance with the plans and sections approved by the Government, and is only to be a single line at present; thus the tunnels are to be constructed for a double line. The railway and everything connected with it is to be the property of the Government, but the rolling stock and the stores will belong to the concessionnaire, with the understanding that they are not to be removed except to be replaced for the advantage of the public service. In return for the obligations which the concessionaire takes upon himself by this contract, the Government concedes for ninety-nine years the working of the railway, as well as any branches which may bring traffic, the concessionaire undertaking at the end of the time to give up the railway in good working condition, the rolling stock and the stores to be taken at a valuation. At any period after the first five years, the Government may purchase the whole concession on certain conditions provided for. The subsidy, which forms the basis of the competition, will be paid at the opening of the line; but this does not apply to branches, for which the Government will neither grant a subvention nor guarantee the profits. If the concessionaire should not construct branches, the Government reserves the right to make them or to concede them to other companies. The Government undertakes not to grant a concession, during the ninety-nine years, of any parallel line at less distance than forty kilometers (twenty-five miles), without the ascent of the original concessionaire who will besides enjoy the following advantages:—He will be exempt from all tax for the first twenty years, and the Government undertakes not to impose any special contribution during the whole of the ninety-nine years; he will have the entry free of taxes of all articles necessary to the construction or working of the line until its completion; and this exemption will be continued during the first two years of working as far as engines and fuel are concerned; lastly, the Government grants all the land belonging to the State which may be required for the line, as well as all buildings and woods that may exist upon such land, but expropriations must be settled privately or by law. The passengers, goods, and cattle rates, will be established on the base of those now in force on the Northern and Eastern of Portugal lines, which belong to a French Company.

Working Steep Grades.—A novel system of working trains on steep railway gradients by locomotive engines has been patented by Mr. Graham Stevenson, of the firm of Dick and Stevenson, Airdrie, and Mr. John Reid, manager of the Provanhall collieries, near Glasgow. The apparatus has just been erected at the collieries named, and put into operation during the past week.

The incline selected for the first application of this system leads downwards from the main rails of the Baillieston branch of the Caledonian Railway to two pits belonging to these collieries, about three quarters of a mile distant, with an average gradient of about 1 in 13, and ranging between 1 in 11 and 1 in 15. About six years ago Mr. Stevenson's firm constructed two powerful tank locomotive engines to work this incline and marshal the trucks of coal before entering the main line; and during that time the engines have performed the work with remarkable success, considering the extraordinary gradients over which they had to travel—the steepest, perhaps, with one exception, worked by locomotive power in the kingdom.

The traffic from the pits has so increased of late as to make it impossible for the engines to overtake it, and the construction of a third engine, or some other means of assisting the two, came to be a matter for consideration. With the latter view it was proposed to erect a small stationary engine, working a wire rope, to contribute to the power of the locomotives, or occasionally to draw a few trucks independently of them; but in place of a stationary engine, the idea of stationary gearing which might be acted on by one of the locomotive engines, occurred to the patentees, and this idea was realized, as we have stated, and has been put into practical operation recently. Since that time the machinery has been inspected at work by a large number of engineers and colliery proprietors, many of whom have expressed decidedly favorable opinions regarding it. The efficiency of the system, together with the simplicity of the arrangement, will probably insure for the system a large adoption where the nature of the ground involves inclines of exceptional steepness, and at other parts admits of the use of locomotives. In such instances stationary engines will be entirely avoided, and no additional working expenses incurred more than if the whole line were worked straight through by locomotives.

The winding drum and its gearing are mounted in suitable bearings on framing fixed in a stone-cased excavation below the line of rails on which the locomotive is brought to the spot. The shaft of the winding drum has fast on it a spur wheel in gear with a pinion on an intermediate shaft, which has also fast on it a pinion in gear with a pinion on one of a pair of shafts. These shafts have wheels fixed on them, with their uppermost parts at the level of the rails, and with cranks on them connected by rods. The rails are cut away at the parts where the tops of the wheels are, and when the locomotive, having two pairs of coupled wheels, is run into position up against a buffer bar, and secured there by a screw, its four wheels rest on the four wheels below, the entire weight of the locomotive serving to impart driving power by adhesion. Then, on the locomotive being made to drive its own wheels, these, acting frictionally on the wheels below, drive the winding gearing. The rails form part of a siding, whilst the winding drum is on the line of the incline. When the train is brought to the top, the locomotive is freed from its anchorage, runs out, and engages the train on the level, disposing of it as desired. In lowering the empty trucks down the incline, the pinion is disengaged, and the drum controlled by the friction strap and lever. The amount of work capable of being performed with the new arrangement is four times greater than before, when the delays consequent on running the locomotives up and down the incline, shunting, coupling, standing, &c., are taken into account, the cost of labor remaining the same, whilst the wear and tear of the rails and engines is very greatly diminished.

ENGINEERING STRUCTURES.

THE TAY BRIDGE.—At the last meeting of the Edinburgh and Leith Engineers' Society, a Paper was read by Mr. A. Grothe, C.E., on the appliances used at the Tay Bridge. He described the piers, which are founded upon rock, and which consist of two cylinders (each nine feet in diameter), and the method of building, floating out, and lowering them into the place which they have permanently to occupy. Afterwards Mr. Grothe noticed the construction of the piers for the 245 feet spans, which are founded upon a layer of gravel sixty three feet under the river bed. These cylinders are thirty-one feet in diameter, and, when floated, were hanging between two barges forty feet high, and having a weight of nearly 200 tons. The lower twenty feet of them have a lining of brickwork to give that part of the pier stiffness and weight. The top part consists of iron, and is only temporary. These are lowered to the river bed, and then further sunk by pumping the sand out from the inside by an apparatus invented by Mr. Reeves one of the assistant engineers at the bridge, which exceeds all other means, previously used, in cheapness and efficiency, and will, it is thought, as it becomes known, supersede in many cases other modes of dredging. Lastly was described the construction and floating out of a heavy block of brickwork on to the top of the filled up cylinder. In answer to a question, Mr. Grothe stated that, in his opinion, it would not have been judicious to build the bridge for a double line all at once, inasmuch as it would have added seventy-five per cent. to the cost, and at least two years to the time of constructing. As it is, a second bridge can always be built by the side of the first, and at a cost not exceeding the seventy-five per cent., the experience gained in building the first representing a saving of twenty-five per cent. for the second. In the meantime the company have the use of the present bridge, and save a large sum as interest on capital while building.—*Architect.*

RAILWAY STATION ROOFS.—Messrs. Andrew Handyside & Co., of Derby and London, are at present engaged in making the iron roofs of four railway stations all of some importance and interest. At Glasgow, for the Union Railway at the new St. Enoch's Square Station, the roof is a large single span of 198 feet and 518 feet long, of somewhat similar construction to that of St. Pancras, London, which is 240 feet span and 689 feet long. The main ribs in the Glasgow roof weigh thirty-seven tons each, and the total weight of ironwork is 1,460 tons. Mr. Blair (since deceased) was the engineer under whom the construction of this station was commenced. Messrs. Handyside & Co. expect to finish the ironwork soon after Christmas, and the station will be completed during the summer. At Manchester the three railway companies, the Midland, the Great Northern, and the Manchester, Sheffield, and Lincolnshire, are about to build a large joint station under the superintendence of Mr. Charles Sacre, the engineer of the last-named company, and have ordered from Messrs. Handyside & Co. the iron roof. This roof again is of the same kind as at St. Pancras, but larger than at Glasgow, having a span of 210 feet and a length of 550 feet, the weight of ironwork being no less than 2,400 tons. This station is to be completed in 1878. At Middlesbrough a new station is being constructed for the North-Eastern Railway Company from the designs of Mr. W. Peachey, architect to the company, and the roof, which Messrs. Handyside & Co. have been making at Derby, is now nearly all erected by them at the site.

From advance proofs of the new edition of Mr. Ewing Matheson's "Works in Iron" which is to appear at Christmas, we have the following particulars of this roof:

"The station is 309 feet long, covered for 180 feet of that length by two spans, one of seventy-four feet (in the clear), and one of forty-three feet two inches, and for the remainder by the larger span only. The arches are pointed in a somewhat Gothic style, and are not tied or trussed, the thrust outwards being taken by the walls, which are sufficiently buttressed by outer buildings. The main ribs are placed twenty feet two inches apart, and spring from stone columns or pilasters attached to the walls, and from pairs of iron columns where the two spans meet. The pairs of iron columns are connected longitudinally by wrought-iron box girders pierced and ornamented with pateræ, and with ornamental cast-iron spandrils. The ribs for the seventy-six feet span are formed as triangulated ribs two feet deep, with flanges twelve inches wide, the upper flange being composed of two plates $\frac{3}{8}$ inch thick, rivetted to a T iron 5 inches × 4 inches × $\frac{1}{2}$ inch, and the lower flange of one plate $\frac{3}{8}$ inch thick attached to a similar T iron. The diagonals are channel bars $2\frac{1}{2}$ inches × $1\frac{1}{2}$ inch × $\frac{1}{2}$ inch. There are eight lines of purlins in the large span, each made as a lattice girder 1 foot 6 inches deep, widened out at the ends to the width of the arched ribs which it intersects. Upon the purlins are placed intermediate rafters, which are single T bars 4 inches × 4 inches × $\frac{1}{2}$ inch, the feet of these rafters resting at one side on the wall, and on the other upon the girders between columns. At the crown of the arch is a raised ventilating roof formed of cast iron spandrils placed on the main ribs, having wood louvres at the sides, and covered by slate on timber rafters. From the springing to the second line of purlins the roof is covered with slates or boarding, and from these upwards to the sides of the ventilating roof, by glass in iron sashbars. The glass covering terminates at the distance of one bay from each end, the portions thus left being covered with zinc upon boarding. The main ribs for the forty-three feet span are similar to the large ribs but smaller, the rib being eighteen inches deep, and the flange plates nine inches wide. There are six lines of purlins, but these are only one foot two inches deep, the intermediate rafters being similar to those in the larger span. At each end of the station two main ribs are placed close together to carry the screen. These screens are formed of wrought-iron framing glazed wooden sashes, and reach to within fifteen feet three inches of the rail level. There are some small side roofs, and other minor structures, but exclusive of these, the weight of the ironwork described above is as follows:

	tons.
In main ribs for large span...........	155
In purlins " "	55
In intermediate rafters for large span.	20
In ventilator and other ironwork.....	26
In main ribs for small span..........	30
In purlins " "	20
In intermediate rafters for small span.	9
In box girders between columns......	10
In other ironwork..................	5
Eight pairs of cast-iron columns......	20
Cast-iron spandrils between columns and longitudinal stays between principals........................	52

The gutters are of lead,

A new terminal station is being constructed at Cape Town, South Africa, under the superintendence of Mr. R. E. Brounger, engineer to the railway company there. The same type of arched roof as at St. Pancras has been adopted but on a small scale, as the span is but seventy-seven feet and the length 256 feet nine inches, divided into thirteen bays of nineteen feet nine inches. In this case a few manufacturers were asked to submit designs to Mr. C. H. Gregory, who acts for the railway company in England. The design of Messrs. Handyside & Co. was accepted, they having reproduced, with certain modifications, the roof over the Drill Hall at Derby which they erected in 1870. The Cape Town roof will be covered by zinc on boarding, except at a raised ventilating roof in center, which will be covered with glass. The ironwork will weigh nearly 200 tons.

THE MARGUERITE BRIDGE AT BUDAPEST.—The preparation of plans for this great work was undertaken in 1871. The chioce of system adopted was left to the concurrent opinion of the engineers; but the Government imposed the condition that the openings should be sixty-seven meters wide, and fourteen meters high above the "zero" of the scale, so as not to hinder navigation. More than thirty-five plans were sent for competition; those of Ernest Gouin & Co., of Paris, were adjudged the best, and they were awarded a prize of 10,000 francs.

The contract for the construction was signed in the spring of 1872, and the work itself commenced in 1873; the formal inauguration of the bridge took place on the 30th of April last.

The total length of the bridge is 570 meters, and its width 17 meters; this bridge is formed of six arches, three at each side of the river, of which the openings are respectively 74.83 meters and 88 meters.

The centers have a radius of 135 meters; they are of wrought iron, and bear plates on which rest the Macadam and the wooden pavements.

The construction consumed 7,000,000 kilog. (15,400,000 lbs.) of wrought and cast iron, 40,000 cubic meters of masonry, among which were 4,500 cubic meters of granite, and 5,000 of other kinds of cut stone.

The iron-work for the centers was made in the shops of the Batignolles Construction Society, under the direction of Mr. Gouin; they were carried to Budapest direcly by railroad, without transhipment. The granite came from the Bavarian frontier. In order to give the bridge a monumental character, the piers were ornamented with allegorical figures, three times the size of life; and with high candelabra of cast metal, bronzed.

The architect of the royal palace, Mr. Chabral.Wilbrod, was charged with the architectural work of the bridge; the sculpture is by Thabard, and the cast ornaments by Durenne. The designs and calculations were made by Mr. Godfernaux; finally, the entire surveillance of the works at Pesth were confided to Mr. Fouquets, chief engineer of the house of Gouin & Co.—*Polytechnic Review.*

ORDNANCE AND NAVAL.

JAPANESE WAR SHIPS.—The Imperial Japanese Government is having an ironclad corvette built in this country. She is of 3,700 tons displacement, 220 feet length between perpendiculars, 48 feet breadth, extreme, and 28 feet 8 inches depth in hold. Her engines are to be on the compound principle, twin screws, with horizontal cylinder and surface condensers. They are to develop 3,500 indicated horse-power, and are estimated to drive the ship at 13 knots. The armament is to be supplied by Krupp, and will comprise four 24 cm. ($9\frac{1}{4}$ inch) 15-ton guns, to be carried in a midship battery on the main deck, and two 17 cm, ($6\frac{3}{4}$ inches) $5\frac{1}{2}$-ton guns on the upper deck. The upper deck guns are carried amidships and are arranged to fire right ahead, on the broadside, and right astern. They are unprotected. The battery guns are placed at the four corners of the battery, and have very considerable fore and aft training in addition to the broadside fire. The armor on sides is 9 inches at the water-line and 7 inches elsewhere amidships; on the battery 8 inches at the Port sills and 7 inches elsewhere. The vessel is to be barque-rigged, with about 12,000 square feet of plain sail. The same Government is also having built here two composite corvettes, which are to have a thin strake of armor ($4\frac{1}{2}$-inches) at the water-line in wake of engines.

THE CHILIAN IRONCLADS ALMIRANTE COCHRANE AND VALPARAISO.—The Chilian ironclads, Almirante Cochrane and Valparaiso, are sister ships, built from Mr. Reed's designs by Earle's Shipbuilding and Engineering Company, Hull. They were completed last year. The principal dimensions are—length between perpendiculars, 210 feet; breadth, extreme, 45 feet 9 inches; depth in hold, 28 feet 10 inches; displacement, 3,400 tons. The engines are by Messrs. John Penn and Sons, of Greenwich, and are twin screw on the compound principle, with horizontal cylinders and surface condensers. They develop collectively 3,000 indicated horse-power, giving a mean speed of 13 knots. The armament consists of six $12\frac{1}{2}$-ton guns by Sir W. Armstrong & Co., in a midship battery. The battery is arranged with embrasures, so that the foremost gun on either side can fire right ahead, and the aftermost gun on either side right astern, with sufficient training to enable them to fire slightly abaft and before the beam respectively. The midship gun on either side also fires from an embrasure port which gives it a training of from 20° abaft the beam to 70° before it. The armor on sides is 9 inches at the water-line and 6 inches elsewhere amidships, tapering forward and aft. On the battery the armor is 8 inches at the port-sills and 6 inches elsewhere. Protective deck plating $\frac{3}{4}$ inch thick is fitted before and abaft the battery on the main deck. These ships are barque rigged, and carry 12,000 square feet of plain sail.

DOING IT QUICKLY.—Some extraordinarily rapid passages across the Atlantic have been recently made by the steamships of "The White Star" line. The Britannic is really at this moment the fastest ocean steamer afloat, as will be seen from the following record of her recent voyages. Under the command of Captain Thompson, she has for four voyages in succession, steamed from Queenstown to New York, and *vice versa*, under eight days, maintaining a remarkable uniformity of speed. The following is the abstract in question:—

OUTWARDS.

Voyage 1876.	d.	h.	m.
10—June	7	16	36
11—July	7	19	57
12—Aug	7	20	46
13—Sept	7	17	37
Average	7	18	44

HOMEWARDS.

Voyage 1876.	d.	h.	m.
10—June	7	19	48
11—July	7	22	31
12—Sept	7	22	55
13—Oct	7	16	23
Average	7	20	25

On the four outward trips the Britannic ran a distance of 11,216 nautical miles, being an average of 2,804 per trip, which gives a speed of little over fifteen knots per hour, or 360 knots per diem. Homewards she steamed 11,549 nautical miles, or 2,887 per trip, equal to 15.32 knots per hour, or 367.68 per diem. We believe there is nothing on record to parallel this performance. It is fair to add that the success of the ship is in great part due to the efficiency of the four cylinder compound engines, fitted by Messrs. Maudslay & Field to the Britannic. These engines are of the overhead type, the high-pressure cylinder being above the low-pressure cylinder.

THE 80 TON GUN.—The Committees on Heavy Guns and Explosives entered in December on a series of experiments with the 80-ton gun at Shoeburyness with a view, however, of testing not so much the gun itself as the service projectiles. The programme consisted of five rounds of common shell, fired over water to try the strength of the shell; five rounds of Palliser projectiles, fired over the sands for range and accuracy; and two rounds of common shell, fused and filled with powder, fired against a wooden target to test the efficacy of the fuses. The principle on which these fuses are constructed is that of a loose detonating ball in a small chamber. When the shell is suddenly checked in its flight by contact with any object, the ball is thrown forward against the front of the chamber and exploded, igniting the powder-charge and bursting the shell. To this end, however, it is necessary that the projectile shall receive a check; and as it is doubtful whether the unarmored sides of wooden ships would interpose any appreciable obstacle to the passage of a 1,200 lbs. shot impelled by the heavy charge of the 80-ton gun, it is necessary to make investigations, and if the fuses fail to act under circumstances which are liable to occur in action, they will have to be made more sensitive. The firing on Wednesday was intended to test the gun for range and accuracy, especially when the projectiles were fitted with Lieutenant Gould-Adams's automatic gas-checks. It was necessary that the tide should be well off the sands and the distant range clear before practice could begin. There was considerable delay before the inevitable coasters could be got well away from the probable path of the projectiles, but when everything was finally ready the gun was laid at an elevation of four degrees. Judging from the time of flight, which was carefully taken by Captain O'Callaghan as 6.9 seconds, the shot must have travelled about 3,900 yards before striking the sand. As this is some 200 yards in excess of the distance reached with the same elevation when the gun was last tried, it may fairly be assumed that the new gas-check had something to do with the result, especially as each of the succeeding rounds occupied within a fraction the same time in its flight. With the second round there was considerable delay, caused by a slight defect in the loading-gear and the failure in two or three of the exploding tubes. When the second and third shots had been fired, however, the wonderful accuracy of the huge gun was clearly demonstrated, as examination showed that these two shells had fallen on the lip of the crater ploughed in the sand by the first projectile. With the fourth and fifth rounds, however, even better results were obtained, the shells falling absolutely in the original crater. The gas-checks answered perfectly, with the exception of one round, when the flanges failed to clip and the metal ring became detached from the shell.

BOOK NOTICES.

ANALYSE INFINITESMIALE. DES COURSES DANS L'ESPACE. Par M. L'Abbe Aoust Paris: For sale by D. Van Nostrand. Price $4.40.

This is designed to satisfy the rapidly increasing taste for works in the highest analysis.

The work is divided into two books each of which is subdivided into sections and chapters. A knowledge of the most advanced Analytical Geometry of our colleges is necessary to read with satisfaction the present work.

YACHT DESIGNING: A Treatise on the Practical Application of the Scientific Principles upon which is based the Art of Designing Yachts. By Dixon Kemp. London: The Field Office. For sale by D. Van Nostrand. Price $31.50.

To judge by the dimensions of this volume we should conclude that Yachts were to be classed among the highly important, if not absolutely necessary, adjuncts of civilized life.

The work is a large quarto and unexceptionable in its mechanical execution. The illustrations are plain, but apparently carefully exact and made with reference to aiding in practical designing and building.

There are many applications of the rules fully worked out, and embodying as these rules do the elementary principles of wave lines and resistances to bodies moving through water, have a wider application than that of the Author's subject.

Many details of celebrated Yachts are given both by text and plates.

NOTES ON LIFE INSURANCE. By GUSTAVUS W. SMITH. Third Edition: Revised, Enlarged and Re-arranged. New York: D. Van Nostrand. Price $2.00.

No work on this subject has earned such trustworthy encomiums as the earlier editions of this book.

The subjects in their order are presented in the following table:

Part I Theory—Net Premiums; Trust Fund Deposit or "Reserve"; Amount at Risk, Valuation of Policies; Annuities; Construction of Commutation Columns; Joint Lives.

Part II. Practical Life Insurance—General Management; Variety in Plans of Insurance; Gross Valuation; Net Valuation; Disposition of Deposit, when Renewal Premium is not paid; Annual Statements.

Appendix—Net Premuims; Deposit; Amount at Risk; Annuities paid oftener than once a year; Summary; Formulas and Tables. The Appendix is a mathematical discussion of the above topics.

POCKET BOOK ON COMPOUND ENGINES. By N. P. BURGH. London: N. P. Burgh. For sale by D. Van Nostrand. Price $3.75.

To feel any confidence in Mr. Burgh's formulas or tabulated results, the reader should carefully omit to read the Author's First Chapter. A sample or two will sufficiently explain the reason of this recommendation:

"Steam is an elastic gas of more or less density, according to the proportions of its constituents—as, for example, should the heat be reduced by cooling, the same quantity of water is increased *in its effect*, and thus elasticity is reduced, the pressure of water in steam being in all cases a known constant, while the pressure of heat is more or less increased or reduced by circumstances."

Again: "Let us think, now, what keeps this globe of ours in motion? Why light! as, for example, see Crooke's Radiometer." Then comes the question, Where does light come from? "Why from Electricity, which is the gift of the Great Creator."

The practical science of Mr. Burgh is, however, much better than his theory. There is no doubt but he enjoys lucid intervals when he gets squarely down to his figures, and his book contains much that is very valuable.

WEATHER CHARTS AND STORM WARNINGS.—By ROBERT H. SCOTT., M. A., F. R. S. London: For sale by D. Van Nostrand. Price $1.75.

A small treatise on an extensive subject. It contains a brief discussion of the theory of Cyclones; too brief to be at all satisfactory to an American reader, who is familiar with the fact of the detection of the first development of a storm and the record of its progress for many hundred miles.

The instruments employed in observation are briefly described and some minature weather maps of Great Britain are given. Were it not for these maps which exhibit some roughly drawn isobaric lines, it might justly be inferred that the science of meteorology in England had advanced just to that point at which the theory that the weather changed at the lunar quadratures, was deemed unreliable.

On the Strength of Bridges and Roofs.—By S. H. Shreve, C. E. Second Edition (Revised). New York: D. Van Nostrand. Price $5.00.

This excellent work has justified the estimate of its value when it first appeared. A second edition revised by the author is now published.

No other work covers so much ground with so short a range of mathematical work. The student who is familiar with algebraic equations of the second degree, can understandingly read the treatise throughout. If he be furthermore familiar with the "Doctrine of Moments" and the principle of the "Triangle of Forces" he may soon familiarize himself with the analysis of all kinds of framed structures.

A Map of the Railway Systems of the Eastern Provinces of Canada. Prepared by the Hon. The Minister of Public Works.

We are indebted to the kindness of Mr. William Kingsford, Engineer in charge of the Canadian Railways, for an early copy of the above map.

It is an elegant sample of execution, and on a liberal scale of dimensions. The representation of different railway lines by different colors is a neat device and much facilitates ready reference.

Pioneer Engineer. By Edward Dobson, C. E. London: For sale by D. Van Nos-Price $5.25.

This work is designed for engineers of some experience, and relates to operations connected with the settlements of waste lands in new countries. It embraces all kinds of work that are likely to engage the attention of engineers in any climate. It is, notwithstanding the design of the author, exceedingly rudimentary and very brief.

The illustrations are excellent and numerous

A Book on Building, Civil and Ecclesiastical. By Sir Edmund Beckett, Bart. London. For sale by D. Van Nostrand. Price, $ 3.75.

This is a popular treatise on such styles of architecture as are practiced at the present time. The work is written in a peculiar, lively strain which is the author's own, and which holds the reader's attention. The writer is never dull although in some places a little obscure. He treats the old authorities in Architecture with but little respect, and it must be acknowledged affords his readers just as little.

There is a healthy disdain of shams manifested throughout, and a thorough knowledge of the practical phase of building of all styles and ages. The illustrations are few and of medium quality.

Glasgow Science Lectures. London & Glasgow. William Collins, Sons & Co. For sale by D. Van Nostrand.

The series contains lectures before unscientific audiences by prominent scientists.

The Dawn of Animal Life: By Prof. W. C. Williamson, F. R. S.

Chemical Elements: Prof. S. H. E. Roscoe, F. R. S.

Is Man an Automaton ? W. B. Carpenter, LL. D., F. R. S.

Coal and Coal Plants: Prof. W. C. Williamson, F. R. S.

Recent Researches into the Chemical Constitution of the Sun: By J. Norman Lockyer, F. R. S.

Kent's Cavern: Wm. Pengelly, F. R. S.

Navigation: Sir Wm. Thompson, LL. D.

Water Supply Engineering. By Col. J. T. Fanning, M. A. S. C. E.

D. Van Nostrand has in preparation a work on Water Supply Engineering, adapted entirely to American practice. It will form a comprehensive Treatise on the Theory and Practice of Gathering and Storing Water for Power and Domestic Use, Clarification of Water, Flow of Water in Pipes and Canals, Raising of Water by Power, and on the Practical Construction of Reservoirs, Weirs, Dams, and Pipe Systems for the Distribution of Water in Cities and Towns. It will make a volume of about 400 pages, octavo, fully and amply illustrated with designs and diagrams.

MISCELLANEOUS.

Father Secchi has written a letter to the French Academy of Sciences on the "Hydraulics of the Ancients." The monuments he mentions have been mostly discovered by him in the environs of Rome. The first mentioned by him is an aqueduct built at Alatri, 200 years before the Christian era. It is an inverted syphon, its lowest point being 101 meters below the orifice from which the water flowed into the town; so that it sustains at its bottom a weight of at least eleven atmospheres. The pipes of this aqueduct are of earthenware, buried in a thick bed of concrete; they were very firmly joined together along a length of 7½ miles. This work seems to have been the model on which Vitruvius founded his description of syphon aqueducts. The second remarkable relic of antiquity found at the same place is a complete system of drainage composed of enormous porous stone-ware pipes, a meter in length, fourteen centimeters in diameter, and only two in thickness. This was done to dry up a plain intended for military manœuvres. Next come inclined planes expressly laid down on substantial foundations and near the top of a mountain, in order to collect rain water on a large surface, with a basin to purify it, and cisterns to preserve it. This was done to provide the town of Segni with potable water. Then follow contrivances of the ancients for turning the water filtering through porous ground into the acqueducts by turning the clayey strata to account. They used also to rid water of its carbonates of lime by boiling, then cooling it again by applying snow to the outside. They likewise had an ingenious way of cooling their "aqua tepular," which was too warm for drinking after it had been brought over to the Capitol. Father Secchi has discovered the spring whence it came, and found that it marks 18 deg. Cent.—64 Fah.—in winter. The Romans used to mix it with water from the Julia, which only marked eleven deg. The other spring, now called "Preziosa," issues from an old volcanic crater.

AIR IN MINES.—At the last meeting of the North Staffordshire Mining Institute a paper by Mr. Wardle, of Burslem, was read on this subject.

In the course of it, Mr. Wardle said the temperature of the earth increased as they descended at about 1° Fah. for every 50 feet to 60 feet. At the deep coalpit at Dukinfield the temperature was constantly 75° Fah. at a depth of 2,151 feet, and at a depth of 17 feet it was only 1° Fah., which gave an increase of 1° Fah. for every 89 feet only. The average degree of temperature of the earth was 1° Fah for every 55 feet in descent to a depth of 1,800 feet, and afterwards 1° Fah. for every 44 feet. At 10,060 feet the temperature would be 212° Fah. provided all other circumstances remained the same; at twenty miles, 1,760° Fah.; and at fifty miles it would be 4,600° Fah., heat sufficient to melt any known metal. Thus, the deeper the shafts of their coal mines the greater the amount of natural ventilation they would obtain. A current of air, travelling at a speed of 10 feet per second, gave a pressure of .492 lb. to the square foot; at 16 feet, = .989; at 51.34,=6.027; and at 200,=39.2, as experienced on the surface of the earth. These might be described as—first, a breeze; second, a light gale; third, a gale; and, fourth, a hurricane. Increased velocity of wind meant greater friction or higher water-gauge. Air was perfectly elastic; by pressure it could be squeezed into less bulk, and if that pressure were withdrawn, it filled the same space as formerly. Heat had the same effect upon it as pressure. A cubic foot of air weighed 523 grains; a cubic foot of water weighed 1,000 oz.; a cubic foot of watery vapor weighed only 272 grains. So that the more vapor there was in the air the lighter it would be. Friction was estimated by the force required to overcome it. Friction of air increased or decreased in the same proportion that the extent of the rubbing surface exposed to the air increased or decreased. A circular airway offered less resistance in proportion to its area than any other form, because its circumference was less in proportion to its area than the perimeter of any other figure. Airways should be as large and with as smooth a surface as possible. Splitting the air-current was preferable to taking the whole current of air round the workings in one body. Generally speaking, splitting the air increased the quantity of air obtained by a given expenditure of power, but the benefits to be derived from splitting were limited by the area of the shaft.

THE curious glass beads called *aggry*, which are valued in Ashantee like diamonds, and which are found deep in the ground in the Dinkira, Akim, Warsaw, Ashantee, and Fantee countries, are supposed to be of ancient Egyptian manufacture. If so, they prove that the Egyptians surpassed the moderns in some respects in making glass. "The variegated strata," says "Johnson's Encyclopædia," now nearly ready for publication, "of the aggry beads are so firmly united, and so imperceptibly blended, that the perfection seems superior to art. The surfaces of some are covered with flowers and regular patterns so very minute, and the shades so delicately softened one into the other and into the ground of the bead, that nothing but the finest touch of the pencil could equal them. The agatised parts disclosed flowers and patterns deep in the body of the bead, and thin shafts of opaque colors run from the center to the surface." The recent Ashantee war has made the public in England somewhat familiar with these beautiful beads. There is observed in them different colored clays baked together without blending, as well as certain peculiarities of manufacture which cannot be well explained. It is remarkable that these beads bear some resemblance to the celebrated *glain neidyr*, or Druid holy snake beads of glass found in Wales.

ELECTRIC ILLUMINATION.—Although the light now for some time in use in the Northern of France Railway station in Paris is economically obtained by means of the Gramme apparatus, there has been one point upon which improvement has been desired. A single light, as used in Paris, although placed at a great height, necessarily throws many very heavy shadows, which contrast most inconveniently with the blinding intensity of the light within its immediate neighborhood The discomfort attending the brightness of the light has been somewhat relieved by glass shades, but the shadows are, although less severe, still inconvenient. It has hitherto been found impossible sufficiently to multiply the number of lights so as to avoid these defects, but a discovery has recently been made by M. Jablockhoff which seems destined to bring the electric light into common use. M. Denayrouse has brought the discovery before the Academy of Science, and it seems that it offers, with little extra cost, an efficient means of procuring several lights from one source of electricity, and of regulating the positions of the carbon points. The most delicate part of the electric light apparatus has been this adjustment of the distance between the carbon points, and it is here that M. Jablockhoff steps in from quite a new path. Instead of placing the carbons end to end, he places them parallel with each other, and separated by some insulating material. The whole is then placed in a cylinder of refractory material in the form of a double carbon wicked candle. By this arrangement the two carbons burn by their lower extremity, there being no necessity for regulators, as the insulating material keeps them at a constant distance. This material as well as the cylinder is consumed in the same time as the carbons, its volatility augmenting the light. Previous to this discovery it was necessary to have a regulator for each lamp, and at great cost, but now a single source of electricity may feed a number of burners, thus permitting of the most effective distribution of the light.

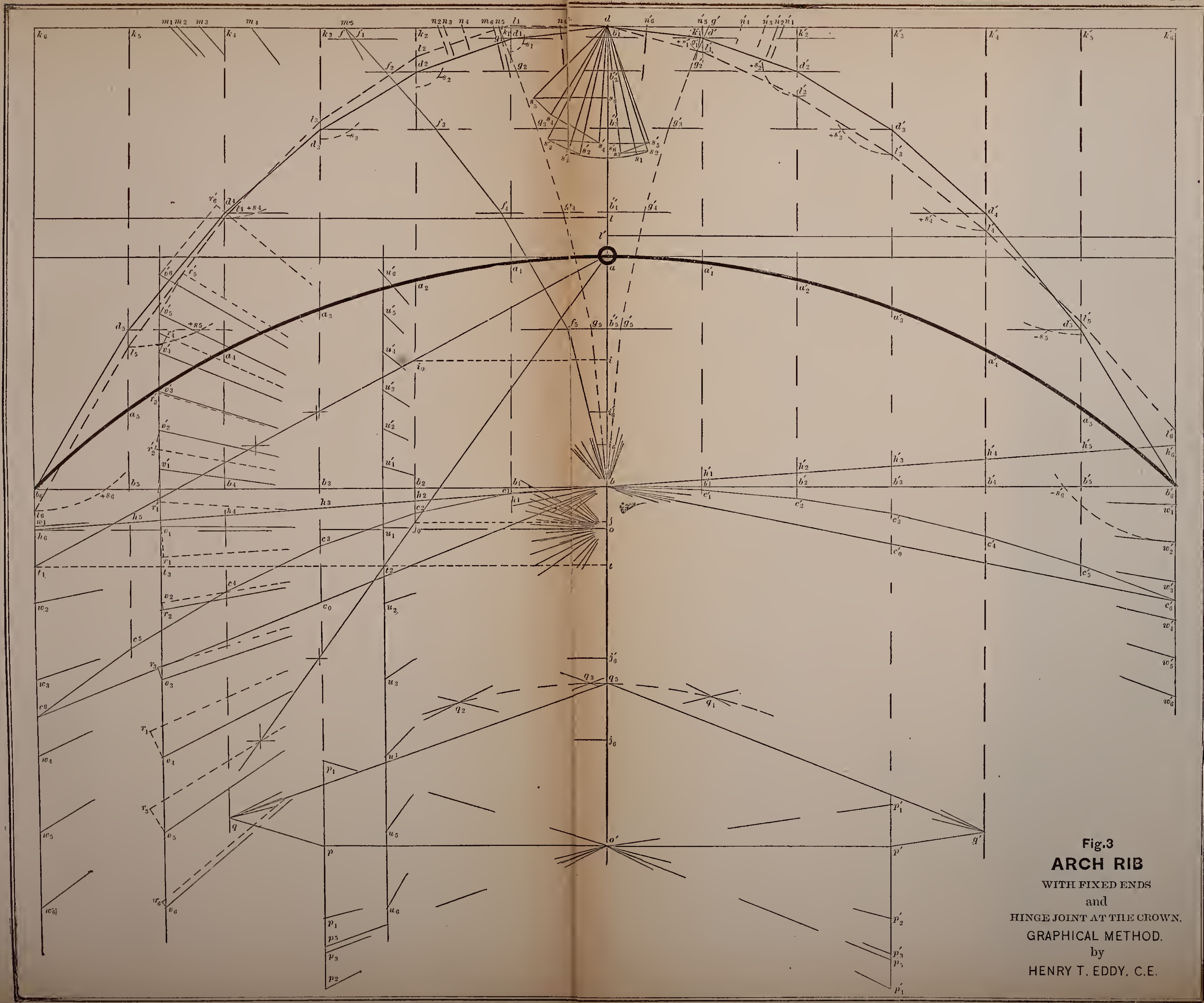


Fig.3
ARCH RIB
WITH FIXED ENDS
and
HINGE JOINT AT THE CROWN.
GRAPHICAL METHOD.
by
HENRY T. EDDY, C.E.

IV.

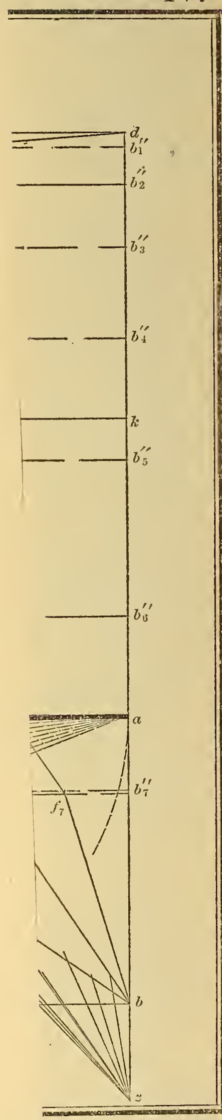
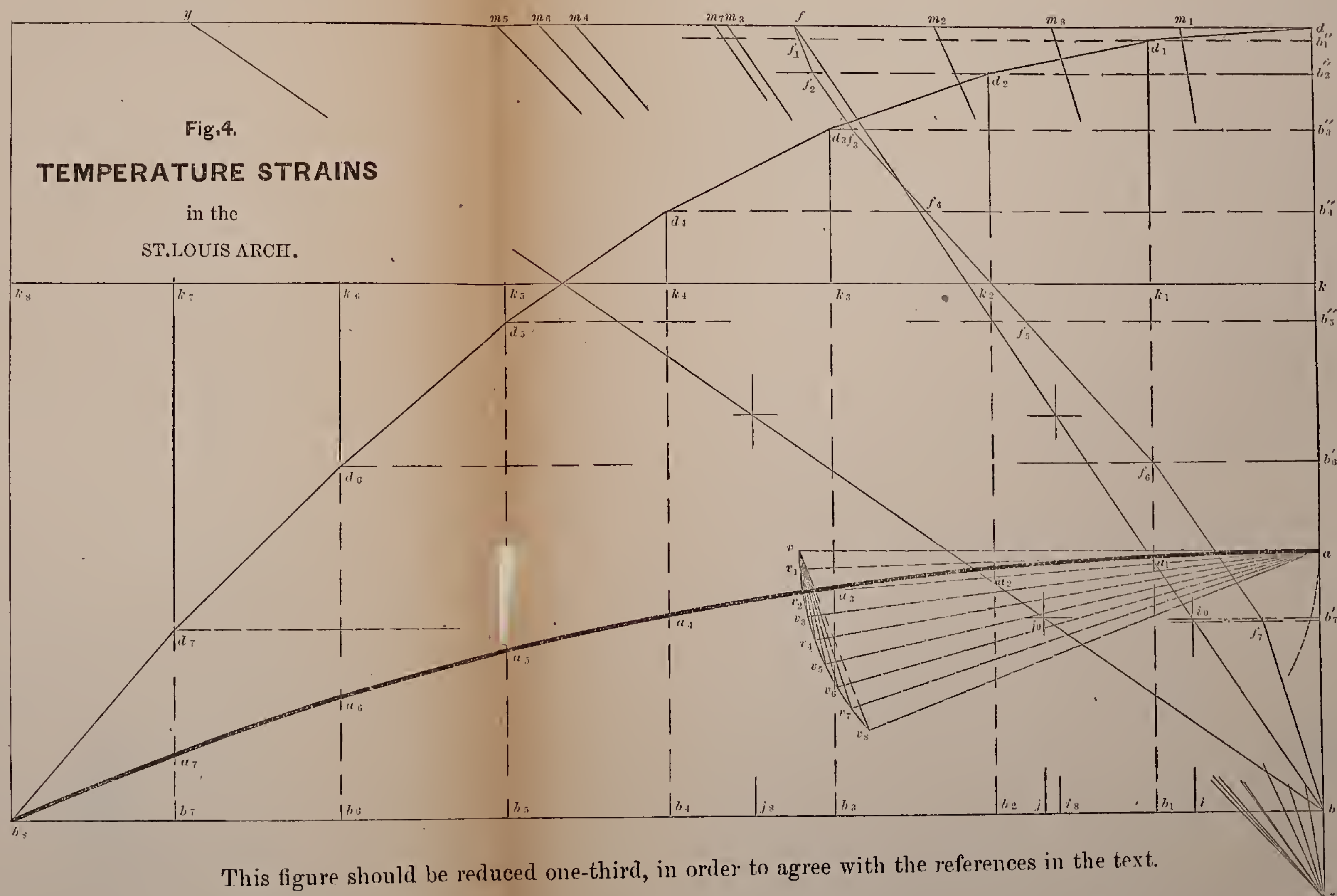


Fig.4.

TEMPERATURE STRAINS

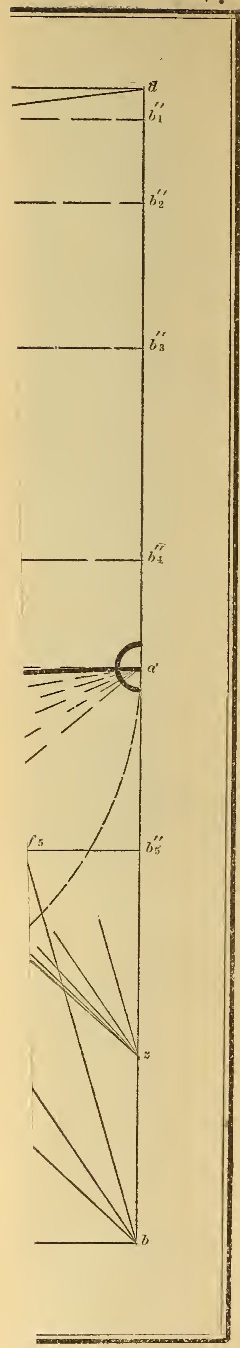
in the

ST.LOUIS ARCH.



This figure should be reduced one-third, in order to agree with the references in the text.

V.



VAN NOSTRAND'S ECLECTIC ENGINEERING MAGAZINE.

NO. XCIX.—MARCH, 1877.—VOL. XVI.

NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

III.

ARCH RIB WITH FIXED ENDS AND HINGE JOINT AT THE CROWN.

LET the curve a of Fig. 3 represent the proportions of the arch we shall use to illustrate the method to be applied to arches of this character. The arch a is segmental in shape, and has a rise of one-fifth of the span. It is unnecessary to assume the particular dimensions in feet, as the above ratio is sufficient to determine the shape of the arch.

The arch is supposed to be fixed in the abutments, in such a manner that the position of a line drawn tangent to the curve a at either abutment is not changed in direction by any deflection which the arch may undergo. At the crown, however, is a joint, which is perfectly free to turn, and which will, then, not allow the propagation of any bending moment from one side to the other. In order that we may effect the construction more accurately, let us multiply the ordinates of the curve a by some convenient number, say 2, though a still larger multiplier would conduce to greater accuracy. We thus obtain the polygon d.

Having divided the span b into twelve equal parts b_1 b_2, etc, (a larger number of parts would be better for the discussion of an actual case), we lay off below the horizontal line b on the end verticals, lengths express on some assumed scale the which weights which may be supposed to be concentrated at the points of division of the arch. If $a\,l$ is the depth of the loading on the left and $al' = \frac{1}{2}al$ that on the right, then $b_6w_1 + b_6'w_6' =$ the weight concentrated at a; $w_1w_2 =$ the weight at a_1; w_1' $w_2' =$ the weight at a_1', etc. Using b as a pole, draw the equilibrium polygon c, whose extremities c_6 and c_6' bisect w_3 w_4 and w_3' w_4' respectively.

Now to find the closing line of this equilibrium polygon so that its ordinates shall be proportional to the bending moments of a straight girder of the same span, and of a uniform moment of inertia I, which is built in horizontally at the ends and has a hinge joint at its center; we notice in the first place that the bending moment at the hinge is zero, and hence the ordinate of the equilibrium polygon at this point vanishes. The closing line then passes through b the point in question. Furthermore it is evident that if we consider the parts of the girder at the right and left of the center as two separate girders whose ends are joined at the center, these ends have each the same deflection, by reason of this connection.

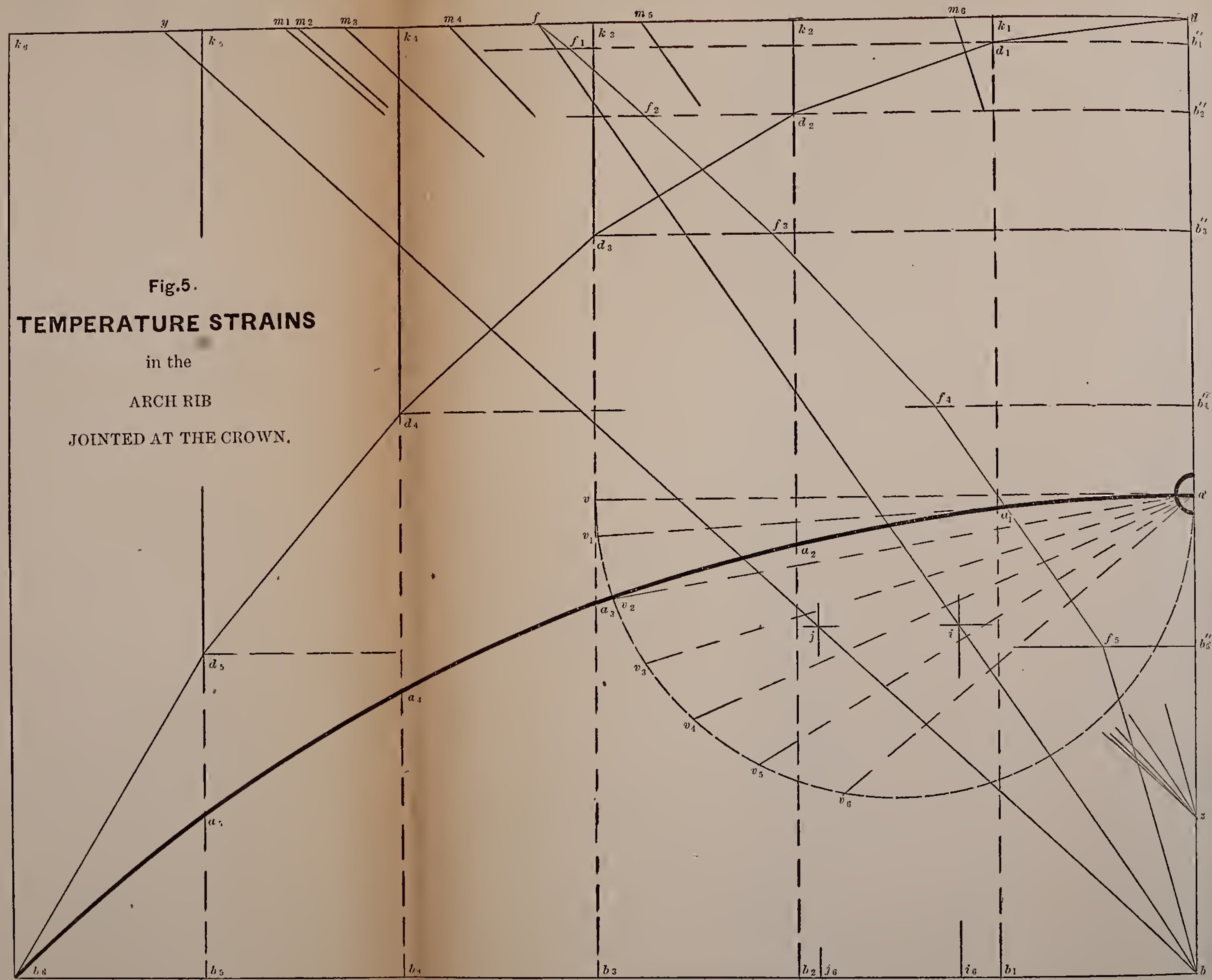


Fig.5.

TEMPERATURE STRAINS

in the

ARCH RIB

JOINTED AT THE CROWN.

This figure should be reduced one-third, in order to agree with the references in the text.

This is expressed by means of our equations by saying that $\Sigma(Mx)$ when the summation is extended from one end to the center is equal to $\Sigma(Mx)$ when the summation is extended from the other end to the center, for these are then the respective deflections of the center. We may then write it thus :

$$\Sigma_{b_6}^{b}(Mx)=\Sigma_{b_6'}^{b}(Mx)$$

The equation has this meaning, viz : that the center of gravity of the right and left moment areas taken together is in the center vertical : for, taking each moment M as a weight, x is its arm, and Mx its moment about the center.

In order to find in what direction to draw the closing line through b so that it shall cause the moment areas together to have their center of gravity in the center vertical through b, let us draw a second equilibrium polygon using the moment areas as a species of loading.

The area on the left included between any assumed closing line as bb_6 (or bh_6) and the polygon bc_6 may be considered to consist of a positive triangular area bc_6b_6 (or bc_6h_6) and a negative parabolic area $bc_3c_6c_0$; and similarly on the right a positive area $bc_6'b_6'$ (or $bc_6'h_6'$) and a negative area $bc_3'c_6'c_0'$.

At any convenient equal distances from the center as at p and p', lay off these loads to some convenient scale. It is, perhaps, most convenient to reduce the moment areas to equivalent triangles having each a base equal to half the span: then take the altitudes of the triangles as the loads. This we have done, so that $pp_1=\frac{4}{3}c_0c_3$, and $p'p_1'=\frac{4}{3}c_0'c_3'$. Now assume, for the instant, that closing line is b_6b_6', which of course is incorrect, and make $p_1p_2=b_6c_6$ and $p_1'p_2'=b_6'c_6'$, then these are the loads due to the positive triangular areas at the left and right respectively, while pp_1 and $p'p_1'$ are the negative parabolic loads.

Take o' as the pole of these loads, then pp' may be taken for the first side of the second equilibrium polygon. Draw $pg \parallel o'p_1$ and $p'g' \parallel o'p_1'$, and then from g and g' draw parallels to $o'p_2'$ respectively. These last sides intersect at g_2. The vertical through g_2 then contains the center of gravity of the moment areas when $b_6\ b_6'$ is assumed as the closing line.

A few trials will enable us to find the position of the closing line which causes the center of gravity to fall on the center vertical. We are able to conduct these trials so as to lead at once to the required closing line as follows. Since, evidently, $b_6c_6+b_6'c_6'=h_6c_6+h_6'c_6'$, it is seen that the sum of the positive loads is constant. Therefore make $p_2p_3=p_2'p_3'$ and use p_1p_3 and $p_1'p_3'$ as the positive loads, in the same manner as we used p_1p_2 and $p'_1p'_2$ previously.

This will be equivalent to assuming a new position of the closing line. The only change in the second equilibrium polygon will be in the position of the last two sides. These must now be drawn parallel to $o'p_3$ and $o'p_3'$ respectively; and they intersect at g_3. The vertical through g_3 contains the center of gravity for this assumed closing line. Another trial gives us g_4.

Now if the direction of the closing line had changed gradually, then the intersection of the last sides of the second equilibrium polygon would have described a curve through g_2, g_3 and g_4. If one of these points, as g_3, is near the center vertical, then the arc of a circle $g_2g_3g_4$, will intersect it at g_5 indefinitely near to the point where the true locus of the points of intersection would intersect the center vertical.

Let us assume that g_5 is then determined with sufficient exactness by the circular arc $g_2g_3g_4$, and draw gg_5 and $g'g_5$ as the last two sides of the second equilibrium polygon. Now draw $o'p_5 \parallel gg_5$ and $o'p_5' \parallel g'g_5$, then $p_1p_5=c_6h_6$ and $p_1'p_5'=c_6'h_6'$ are the required positive loads, and h_6bh_6' is the position of the closing line such that the center of gravity of the moment areas is in the center vertical.

It is evident that the closing line of the polygon d considered as itself an equilibrium polygon is the horizontal line through d, for that will cause the center of gravity of the moment areas on the left and right, between it and the polygon d, to fall on the center vertical.

The next step in the construction is to apply Prop. IV, for the determination of the bending moments.

That Prop. IV is true for an arch of this kind is evident; for, the loading causes bending moments proportional to the ordinates h_2c_2, h_3c_3, etc., while the arch itself is fitted to neutralize in virtue of its shape moments which are proportional to k_2d_2, k_3d_3, etc. The differences of the moments represented by these ordinates are what actually produce bending in the arch.

Now the ordinates of the type hc are not drawn to the same scale as those of the type kd, for each was assumed regardless of the other. In order that we may find the ratio in which the ordinates hc must be changed to lay them off on the same scale as kd it is necessary to use another equation of condition imposed by the nature of the joint and supports, viz:

$$\Sigma_{b_6}^{a}(M_a-M_c)y=\Sigma_{b_6'}^{a}(M_a-M_c)y$$

or $$\Sigma_{b_6}^{d}(M_d-M_c)y=\Sigma_{b_6'}^{d}(M_d-M_c)y$$

The left hand side of the eq. is the horizontal displacement (*i.e.*, the total deflection) of the extremity a of the left half of the arch, due to the actual bending moments (M_d-M_c) acting upon it: and the right hand side is the horizontal displacement of a the extremity of the right half of the arch due to the moments actually bending it. These are equal because connected by the joint.

The construction of the deflection curves due to these moments will enable us to find the desired ratio.

The ordinates kd and hc are rather longer than can be used conveniently, to represent the intensity of the moments concentrated at d_1,d_2, etc, and c_1,c_2, etc.: so we will use the halves of these quantities instead. Therefore lay off $dm_6=\frac{1}{4}k_6,b_6$, $m_6m_5=\frac{1}{2}k_5d_5$, $m_5m_4=\frac{1}{2}k_4d_4$, etc., and also $dn_6=\frac{1}{4}h_6c_6$, $n_6n_5=\frac{1}{2}p_5c_5$, etc.

We use only one-quarter of each end ordinate because the moment area supposed to be concentrated at each end has only one half the width of the moment areas concentrated at the remaining points of division.

Using b as a pole we find the deflection curve f_b due to the moment M_a or M_d and the deflection curve gb due to the moments M_c on the left. On the right we should find a deflection $df'=df$ not drawn, and similarly a deflection dg' not equal to dg.

Now the equation we are using requires that the ordinates hc shall be elongated so that when used as weights the deflections shall be identical: *i.e.*, we must have $df=\frac{1}{2}gg'$. To effect the elongation, lay off $aj=df$ and $ai=\frac{1}{2}gg'$; and at any convenient distance on the horizontals ii_0 and jj_0 draw the vertical i_0j_0; then the lines ai_0 and aj_0 will effect the required elongation. For example, lay off $ai_6=h_6c_6$, from which we obtain $aj_6=k_6l_6$ for the left end ordinate, and similarly $aj_6'=k_6'l_6'$.

The pole distance tt_1, of the original polygon c must be shortened in the same ratio in which the ordinates are elongated. Hence the new pole distance of the polygon e is tt_2.

Since k_6k_6' is the closing line of the polygon e, and is horizontal, the pole of e is o, on the horizontal through h_6; for, h_6w_6 is the part of the applied weight sustained by the left support.

Now if the weight line be moved up to t_2 so that the applied weights are u_1u_1' at the center, etc., and o is the pole, the polygon e may be described starting from d, and it will finally cut off the end ordinates k_6e_6 and $k_6'e_6'$ before obtained. Then will the ordinates of the type de be proportional to the moments actually bending the arch, and the moments will be equal to the products of de by tt_2, in which de is measured on the scale of distance, and tt_2 on the scale adopted for the weights w_1w_2, etc.

The accuracy of the construction is finally tested by taking $\Sigma(ds)^2=0$, an equation deduced from $\Sigma''(M_d-M_c)y=0$, as explained in the previous article upon the St. Louis Arch. It is unnecessary to explain the details of this construction since as appears from Fig. 3 it is in all respects like that in Fig. 2.

Now let us find the intensity of the tangential compression along the arch and of the shearing normal to the arch. Since the pole distance tt_2 refers to the difference of ordinates between the polygons d and e, whose ordinates are double the actual ordinates, if we wish now to return to the actual arch a whose ordinates are halves of the ordinates of d, we must take a pole distance $tt_3=2tt_2$ and move the weight line so that it is the vertical through t_3. Then tt_3 is the actual horizontal thrust of this arch due to the weights; and ov_6 is the resultant stress in the segment a_5b_8 of the arch, which may be resolved into two components or_6 and v_6r_6 respectively parallel and perpendicular to a_5b_6.

Then are or_6 and v_6r_6 respectively, the thrust directly along, and the shear directly across the segment a_5b_6 of the arch. Similarly or_5 and v_5r_5 represent the thrust along, and the shear across the segment a_5a_4, and so on for other segments. These quantities are all measured in the same scale as that of the applied weights.

The shear changes sign twice, as will be seen from inspection of the directions in which the quantities of the type vr are drawn. The shear is zero wherever the curves d and e are parallel to each other. Thus the shear is nearly zero at b_6, at a_2 and at some point between a_2' and a_3'.

The maxima and minima shearing stresses are to be found where the inclination between the tangents to the curves d and e are greatest.

The statements made in the previous article, respecting the position of the moving load which causes maximum bending moments, are applicable to this kind of arch also.

The maximum normal shearing stress will occur for the parts of the arch near the center, when the moving load is near its present position, covering one half of the arch. But the maximum normal shearing stress near the ends, may occur when the arch is entirely covered by the moving load, or when it may occur when the moving load is near its present position, it being dependent upon the rise of the arch, and the ratio between the moving and permanent load.

The maximum tangential compressions occur when the moving load covers the entire arch. The stresses obtained by the foregoing constructions, go upon the supposition that the arch has a constant cross-section, so that its moment of inertia does not vary, and no account is taken of the stresses caused by any changes of the length of the arch rib, due to variations of temperature or other causes. These latter stresses we shall now investigate for both of the kinds of arches which have been treated.

TEMPERATURE STRAINS.

It is convenient to classify all strains and stresses arising from a variation in the length of the arch, under the head of temperature, as such stresses could evidently have been brought about by suitable variations of temperature.

The stresses of this kind which are of sufficient magnitude to be worthy of consideration, besides temperature stresses are of two kinds, viz. the elastic shortening of the arch under the compression to which it is subjected, and the yielding of the abutments, under the horizontal thrust applied to them by the arch. This latter may be elastic or otherwise. It was, I believe, neglected in the computation of the St. Louis Arch, and no doubt with sufficient reason, as the other stresses of this kind were estimated with a sufficient margin to cover this also. Some one has ignorantly suggested that barometric variations have a large effect. But it is believed that there are no other causes than those enumerated which have an appreciable effect.

Taking the coefficient of expansion of steel as ordinarily given, a change of $\pm 80°$F. from the mean temperature would cause the St. Louis Arch to be fitted to a span of about $3\frac{1}{4}$ inches, greater or less than at the mean.

The problem we wish to solve then is very approximately this: What horizontal thrust must be applied to increase or decrease the span of this arch by $3\frac{1}{4}$ inches, and what other stresses are induced by this thrust. In Fig. 4 the half span is represented on the same scale as in Fig. 2. The only forces applied to the half arch are an unknown horizontal thrust H at b_8 and an equal opposite thrust H at a. The arch is in the same condition as it would be if Fig. 4 represented half of a gothic arch of a span $= 2ab$, of which a was one abutment, and b_8 was the new crown at which a weight of $2H$ was applied. The gothic arch would be continuous at the crown, but the abutment a would be mounted on rollers, so that although the direction of a tangent at a could not be changed, nevertheless the abutment could afford no resistance to keep the ends from moving apart, *i.e.* there is no thrust in the direction of ab, any more than there is along an ordinary straight girder.

In order to facilitate the accurate construction, let us multiply the ordinates of a by 3 and use the polygon d instead. Now the real equilibrium polygon of the applied forces H, is the straight line kk_s. By real equilibrium polygon is meant, that one which has for its pole distance, the actual thrust of the arch. As we are now considering this arch, H is the applied force, and the thrust spoken of is at right angles to H. We have just shown this thrust to be zero. We have then to construct an equilibrium polygon for the applied force H with a pole distance of zero. The polygon is infinitely deep in the direction of H, and hence is a line parallel to H. This fixes its direction.

Its position is fixed from the consideration that the total bending is zero, (because the direction of the tangents at the extremities a and b_8 are unchanged), which is expressed by the equation

$$\Sigma(M_d)=0.$$

This gives us the same closing line through k which we found in Fig. 2, and the ordinates of the type kd, are proportional to the moments caused by the horizontal thrust H.

Now lay off $dm_8=\frac{1}{2}k_8b_8$, $m_8m_7=k_7d_7$, etc., as in Fig. 2.

The problem of finally determining H, will be solved in two steps, 1° we shall find the actual values of the moments to which the ordinates kd are proportional, and 2° find H by dividing either of these moments by its arm.

By considering the equation

$$D_y EI=\Sigma(My)$$

given in our first article, in which D_y is the horizontal displacement, it is seen that if the actual moments are used for weights, and EI for the pole distance, we shall obtain, as the second equilibrium polygon, a deflection curve whose ordinates are the actual deflections due to the moments. By actual moments, actual deflections, etc, is meant, that all of the quantities in the equation are laid off to the scale of distance, say *one* n^{th} of the actual size.

Now let the equation be written

$$nD_y\,.\,\frac{1}{n}EI=\Sigma(My).$$

From which it is seen that if the ordinates be multiplied by n, so that on the paper they are of the same size as in the arch, we must use *one* n^{th} of the former pole distance, all else remaining unchanged.

Now for the St. Louis Arch, $EI=$ 39680000 foot tons. Let us take 100 tons to the inch, as the scale of force: and since $bd=3$ inches, the scale of distance n is found from the proportion 3 inches, ∷ 51.8 ft. ∷ 1 : $n=210$ nearly, and $EI \div 100\ n^2=9$ in. nearly, which is the pole distance necessary to use with the actual deflection one half of $3\frac{1}{4}$ in.$=$ $1\frac{5}{8}$in., in order that the moments may be measured to scale. As it is inconvenient to use so large a distance as 9 in. on our paper, let us take $\frac{3}{8}$ of 9 in. $=3\frac{1}{3}$ in. nearly $=dz$ for the pole distance, and $\frac{8}{3}$ of $1\frac{5}{8}$ in. $=4\frac{1}{3}$ in. $=dy$, for the deflection.

Now with z as a pole and the weights dm_8, m_8m_7, etc, draw the deflection curve bf, having the deflection $=df$. The moments M_d must be increased in such a ratio that the deflection will be increased from df to dy. Therefore draw the straight lines bf and by, which will enable us to effect the increase in the required ratio. For example, the moment $dm_1=bi$ is increased to bj, and $dm_8=bj$ is increased to bj_8. Now measuring bj in inches and multiplying by 210 and by 100, we have found that 21000 $bj=1809$ foot tons$=$the moment at d or a.

And again, 21000 $bj_8=3747$ foot tons $=$the moment at b_8.

By measurement 210 $dk=17$ ft. and 210 $bk=34.8$ ft.

$$\therefore H=1809 \div 17 = 106 \text{ tons, } +$$

$$\text{or } H=3747 \div 34.8=108 \text{ tons } -.$$

These results should be identical, and the difference between them of less than 2 per cent. is due to the error occasioned by using the polygon d instead of the curve of the ellipse, and to small errors in measurement. With a larger figure and the subdivision of the span into a greater number of parts this error could be reduced. The value of H found for the St. Louis Arch by computation was 104 tons, but that was not on the supposition of a uniform moment of inertia I, and should be less than the value we have obtained.

Now this horizontal thrust H due to temperature and any other thrusts of like nature due to compression, etc, is of the nature of a correction to the thrust due to the applied weights. Thus in Fig. 2 we found $3ov'$ to be the thrust due to the applied weights, and on applying the correction we must use the two thrusts $3ov'+H$ and $3ov'-H$ as pole distances to obtain equilibrium polygons whose ordinates reckoned from the arch a will, when multiplied by its pole distance, give the true bending moments. The tangential and normal stresses can then be determined by resolution, precisely as in Fig. 3.

If it, however, appears desirable to compute separately the strains due to H, this may be more readily done than in combination with the stresses already obtained. We have already seen sufficiently how the bending moments due to H are found. In fact the moments are such as would be produced by applying H at the point where the horizontal through k cuts the polygon d, for this is the point of no moment, and may be considered for the instant as a free end of each segment, to each of which H is applied causing the moments due to its arm and intensity.

To find the tangential stress and shear, lay off in Fig. 4 $av=H$ and on it as a diameter describe a semicircle, and draw $ar_8 \parallel a_7a_8$, $ar_7 \parallel a_6a_7$ etc.; then will ar_8 be the component of H along a_7a_8, and vr_8 be the component of H directly across the same segment. In a similar manner the quantities of which ar on the type are tangential stresses and the quantities vr are shearing stresses.

The scale used for this last construction is about fifty tons to the inch.

Now H is positive or negative according as the temperature is increased above or diminished below the mean, and these tangential and normal components, of course, change sign with H.

It should also be noticed in this connection that thrusts and bending moments, which are numerically equal but of opposite sign, are induced by equal contractions and expansions.

The stresses due to variation of temperature in the arch of Fig. 3, having a center joint, are constructed in Fig. 5.

It is evident from reasoning similar to that employed for the case just discussed, that the closing line dk_6 of the polygon d is the equilibrium polygon of the thrust H induced by variation of temperature. Suppose we have changed the equation of deflections to the form,

$$mD_y \cdot \frac{EI}{mn^2} = \Sigma\left(\frac{M}{n} \cdot \frac{y}{n}\right),$$

in which, if $mD_y = dy$ and $EI \div mn^2 = dz$, then the moments M and the ordinates y will be laid off on the scale of 1 to n. This is equivalent to doing what was done in the previous case, where m was equal to $\frac{8}{3}$. The remainder of the process is that previously employed.

It should be noticed that we have in Figs. 4 and 5, incidentally discussed two new forms of arches, viz: in Fig. 4 that of an arch having its ends fixed in direction, but not in position; *i.e.*, its ends may slide but not turn, and in Fig. 5, that of an arch sliding freely and turning freely at the ends. The first of these arches has the same bending moments as a straight girder, fixed in direction at the ends, and the second of them has the same bending moments as a simple girder supported at its ends.

UNSYMMETRICAL ARCHES.

The constructions which have been given have been simplified somewhat by the symmetry of the right and left hand halves of the arch, but the methods which have been used are equally applicable if such symmetry does not exist, as it does not, if, for example, the abutments are of different heights.

In particular, for the unsymmetrical arch, its closing line is not in general horizontal, and must be found precisely as that for the equilibrium polygon due to the applied weights.

If, in Fig. 3, the hinge joint is not situated at the center, the arch is unsymmetrical, and the determination of the closing line due to the applied weights, is not quite so simple as in Fig. 3. It will be necessary to draw the trial lines through the joint by which the curve of errors g is found.

Smouldering Fires in Coal Mines.—At the February meeting of the Manchester Geological Society a discussion arose as to the probable connection between smouldering fires in goafs in coal mines and mine explosions. It was observed that eighty per cent. of the explosions occurred between November and February, though it might be thought that the ventilation being slacker in the summer they would be more numerous. Mr. Greenwell thought it was very possibly the result of fire standing in a goaf.

ON BEAMS OF UNIFORM RESISTANCE, THE BEAM FORMING PART OF THE LOADING.

By S. W. ROBINSON, Professor of Mechanical Engineering in the Illinois Industrial University.

Written for Van Nostrand's Engineering Magazine.

In Professor De Volson Wood's admirable text-book on the "Strength of Materials," a chapter is devoted to beams of uniform resistance in which there appear a few novel solutions where the beam itself constitutes the entire loading. Though in a practical point of view, such solutions may seem to possess but little merit, yet in theory they are of much interest; and we know not how soon they may be extended to practical utility.

In the chapter just cited, a few pages following the solutions above referred to, we find the following, under the topic, "Unsolved Problems," viz.: "5. Required the form of a beam of uniform strength, which is supported at the ends, the weight of the beam being the only load. Suppose, also, that it is loaded at the middle." These two cases, as well as several others, are considered in the following solutions:

The present article is confined to the two modes of securing the beam: first, fixed at one end, and free at the other; and second, supported at both ends. In both of these the loading is of three different kinds: first, the beam itself; second, a concentrated load; and third, a uniformly distributed load. The form of beam is limited in three ways: first, depth constant; second, breadth constant; and third, depth divided by breadth constant, or sections similar.

The notation adopted is that of Prof. Wood's book, where

R = modulus of rupture.

b = greatest breadth of beam.

d = greatest depth of beam.

l = length of beam.

δ = weight of unit of volume of material composing the beam.

w = weight of unit of length of the uniform load.

P = the concentrated load,

x, y and u co-ordinates of length, depth and breadth of beam respectively.

$\frac{1}{6}Ruy^2$ = moment of ultimate resistance of beam of rectangular sections, where y = depth.

$\frac{1}{4}Ry^3$ = similar moment for beam of circular sections where y = radius.

As a first example, suppose the

BEAM FIXED AT ONE END AND FREE AT THE OTHER,

the weight of beam, and weight P at free end, being the loading.

With the exception of the moment of P, the equation of moments for this beam is given in Professor Wood's book, 2d edition, p. 193, so that by adding the moment of P, simply Px, gives us

$$Px+\delta d\int u\,dx\left(x-\frac{\int xu\,dx}{\int u\,dx}\right)=\frac{1}{6}Rud^2 \quad (1)$$

which supposes the origin of co-ordinates to be taken at the free end of the beam.

The relation of u and x, required for performing the integrations indicated, is involved in the expression itself, and hence it will be necessary to remove the integral signs by differentiating.

Differentiating twice, cancelling common terms and reducing, we obtain

$$u\frac{6\,d}{Rd}=\frac{d^2u}{dx^2}\cdot =\frac{u}{m} \quad \text{if} \quad m=\frac{Rd}{6\,d}.$$

Multiplying through by du and integrating, we obtain

$$\frac{du^2}{dx^2}=\frac{u^2}{m}+C=\frac{1}{m}(Cm+u^2) \quad . \quad (2)$$

Extracting the square root, solving for dx, multiplying by u, and integrating between limits o and contemporaneous values of x and u, we get

$$\int_o^x u\,dx=\sqrt{m}\int_o^u\frac{u\,du}{\sqrt{Cm+u^2}}$$
$$=\sqrt{m}\left(\sqrt{Cm+u^2}-\sqrt{Cm}\right)\cdot (3)$$

Substituting this for the same expression found in the first differential of equation (1), and we get

$$\mathrm{P}dx+\delta d\,dx\sqrt{m}\,(\sqrt{\mathrm{C}m+u^2}-\sqrt{\mathrm{C}m})$$
$$=\frac{\mathrm{R}d^2}{6}du,\ =\delta dmdu,\ =\delta d\sqrt{m}\sqrt{\mathrm{C}m+u^2}\ dx;$$

The last step requiring (2). Hence,

$$\mathrm{P}=\delta dm\sqrt{\mathrm{C}}.$$

Substituting C in (2), and reducing, we get

$$x=\sqrt{m}\int_o^u\frac{du}{\sqrt{\frac{\mathrm{P}^2}{\delta^2d^2m}+u^2}}$$
$$=\sqrt{\frac{\mathrm{R}d}{6\,\delta}}\ \text{hyp. log.}\left(\frac{u}{\mathrm{P}}\sqrt{\frac{\mathrm{R}\delta d^3}{6}}+\sqrt{1+\frac{u^2}{\mathrm{P}^2}.\frac{\mathrm{R}\delta d^3}{6}}\right)\quad .\ .\quad (4)$$

This is the equation of longitudinal horizontal section of the beam.

Without discussing these equations further at present, we observe that the manner in which C disappeared, and P reappeared after once disappearing, before being required to integrate for x, suggests that a general solution may be effected covering all cases.

To obtain a general solution let k represent the cross section of beam, always considered rectangular. Then $k=uy$, a variable which admits of any assigned relation of u and y. An equation of moments established similarly as was eq. (1), gives

$$\frac{1}{6}\mathrm{R}ky=\mathrm{P}x+\frac{wx^2}{2}+\delta\int kdx\left(x-\frac{\int xkdx}{\int kdx}\right)\ (6)$$

in which the first member is equivalent to $\frac{1}{6}\mathrm{R}uy^2$, the well known expression, for the moment of ultimate resistance of a beam to transverse forces at a point where the breadth and depth is u and y. The second member is the applied moment, with the origin of moments at the section of beam considered, while the origin of co-ordinates is at the free end of beam. Hence Px is the moment of the force P applied at the free end; wx the uniform load over x, and $\frac{wx^2}{2}$ its moment, since the arm is $\frac{x}{2}$; and $\delta\int kdx$ the weight of beam from o to x; with the expression in the brackets its lever arm, found by subtracting from x, the abscissa of the center of gravity of that part of beam between o and x.

Differentiating once, we obtain

$$\frac{\mathrm{R}}{6}\cdot\frac{d(ky)}{dx}=\mathrm{P}+wx+\delta\int kdx\quad .\ (7)$$

which is the shearing stress at any point of the beam, and thus given, according to k; in terms of the tangent, subnormal, or rectangle of y and the subnormal of the curve of the beam. At the free end of beam x and $k=o$ and

$$\frac{\mathrm{R}}{6}\cdot\frac{d(ky)_1}{dx_1}=\mathrm{P}\quad .\ .\ .\ .\ (8)$$

Differentiating again, and (7) becomes

$$\frac{\mathrm{R}}{6}\cdot\frac{d^2(ky)}{dx^2}=w+\delta k\quad .\ .\ .\ .\ (9)$$

Multiplying by $d(ky)$ and integrating

$$\frac{\mathrm{R}}{12}\cdot\frac{d(ky)^2}{dx^2}=wky+\delta\int_o^{ky}kd(ky)+\mathrm{C}\ .\ (10)$$

At the free end of beam $k=o$, and, using equation (8)

$$\frac{\mathrm{R}}{12}\frac{d\,(ky)_1{}^2}{dx_1{}^2}=\mathrm{C}=\frac{3\,\mathrm{P}^2}{\mathrm{R}}\quad .\ (11)$$

Hence, eq. (10),

$$\frac{d\,(ky)}{dx}=\sqrt{\frac{12}{\mathrm{R}}}\sqrt{\frac{3\mathrm{P}^2}{\mathrm{R}}+wky+\delta\int_o^{ky}kd(ky)}\quad (12)$$

so that the tangent subnormal, etc., are always easily found.

Solving for x, we have

$$x=\sqrt{\frac{\mathrm{R}}{12}}\int\frac{d(ky)}{\sqrt{\frac{3\mathrm{P}^2}{\mathrm{R}}+wky+\delta\int_o^{ky}kd(ky)}}+\mathrm{C}'\quad .\ (13)$$

This solution covers a great number of practical examples, twelve of which follow from supposing depth constant, breadth constant, or depth divided by breadth constant, while the loading may be all present, P absent w absent, or w and P absent. The form of beam for some of these examples will be given below. This equation is not always integrable.

But before proceeding to examples let us examine, in a general way, the case of a

BEAM SUPPORTED AT BOTH ENDS,

the loading being the weight of the beam itself. A concentrated load of 2P at the middle, and a uniform load of w per unit over the whole length. The reaction of each support we may call V,= half the total weight of beam and load.

$$\therefore \quad V=P+wx_2+\delta\int_o^{x_2} kdx \quad . \quad (14)$$

where the subscripts, 2, refer to values for the middle point of beam, the origin of co-ordinates being taken at the end.

The equation of moments, established similarly as before, will be

$$\frac{1}{6}Rky=Vx-\frac{wx^2}{2}-\delta\int kdx\left(x-\frac{\int xkdx}{\int kdx}\right) \quad (15)$$

the moment of all the forces acting on beam at one side only of section considered being taken.

Differentiating once gives

$$\frac{R}{6}\cdot\frac{d\,(ky)}{dx}=V-wx-\delta\int kdx \quad (16)$$

and for the middle point of beam,

$$\frac{R}{6}\cdot\frac{d(ky)_2}{dx_2}=V-wx_2-\delta\int_o^{x_2} kdx=P, \quad . \quad . \quad (17)$$

by eliminating V by aid of (14)

Differentiating again, and (16) becomes

$$\frac{R}{6}\cdot\frac{d^2(ky)}{dx^2}=-w-dk\,. \quad . \quad . \quad (18)$$

Multiplying by $d(ky)$ and integrating

$$\frac{R}{12}\cdot\frac{d(ky)^2}{dx^2}=-wky-\delta\int_o^{(ky)} kd(ky)+C \quad (19)$$

At middle of beam (19) and (17) give

$$\frac{R}{12}\cdot\frac{d\,(ky)_2{}^2}{dx_2{}^2}=-w(ky)_2-\delta\int_o^{(ky)_2} kd(ky)+C=\frac{3P^2}{R}$$

whence

$$C=\frac{3P}{R}+w(ky)_2+\delta\int_o^{(ky)_2} kd(ky) \quad . \quad . \quad . \quad (20)$$

Eq. (19) gives

$$\frac{d\,(ky)}{dx}=\sqrt{\frac{12}{R}}\sqrt{C-wky-\delta\int_o^{(ky)} kd(ky)} \quad (21)$$

which gives the tangent subnormal, etc., similarly as before, always obtainable.

Also, solving for x, we have

$$x=\sqrt{\frac{R}{12}}\int\frac{d(ky)}{\sqrt{C-wky-\delta\int_o^{(ky)} kd(ky)}} \quad (22)$$

an equation which is integrable for many practical cases, but not always, as will be seen below.

The present article will be confined to the above two modes of holding or supporting the beam, and we will now pass to practical examples, first considering the

BEAM FIXED AT ONE END.

Case I. Let the depth be constant.

1st. Let all the loading be present. We have

$$k=ud,\ ky=ud^2,\ d(ky)=d^2du$$

and $\int_o^{ky} kd(ky)=d^3\int_o^u udu=d^3\frac{u^2}{2}$

These values in (13) give, observing that for $u=o, x=o$,

$$x=\sqrt{\frac{R}{12}}\int\frac{d^2\,du}{\sqrt{\frac{3P^2}{R}+wud^2+\delta d^3\frac{u^2}{2}}}$$

$$=\sqrt{\frac{Rd}{6\,\delta}}\text{ hyp. log.}$$

$$\left\{\frac{\delta ud+w+\sqrt{\frac{6\,\delta}{Rd}P^2+2wu\delta d+u^2\delta^2d^2}}{w+P\sqrt{\frac{6\,\delta}{Rd}}}\right\} \quad (23)$$

which is the equation of the curve of horizontal section.

When $u=b$, $x=l$, and the resulting expression shows that the length of beam is dependent upon other quantities, such as depth, breadth, density, etc., or these upon the length. For the tangent, we have from (12),

$$\frac{du}{dx}=\text{tang. } i=\frac{1}{d^2}\sqrt{\frac{12}{R}}$$

$$\sqrt{\frac{3P^2}{R}+wud^2+\frac{\delta u^2\,d^3}{2}}. \quad . \quad . \quad (24)$$

At the free end,

$$\text{tang. } i_1=\frac{6\,P}{Rd^2},$$

And at fixed end,

$$\text{tang. } i_2=\frac{6\,P}{Rd^2}\sqrt{1+\frac{Rwud^2}{3P^2}+\frac{R\delta u^2d^3}{6P^2}},$$

which shows that the tangent line makes the greatest angle with the beam at the fixed end, and hence the sides of the beam are concave.

To find whether the curve has asymptotes place $(24)=o$, whence

$$\delta ud=-w\pm\sqrt{w^2-\frac{6\delta P^2}{Rd}} \quad . \quad . \quad (25)$$

Placing thus in (23), we find only the plus sign before the radical to be admissible, and by reduction

$$x'=\sqrt{\frac{\mathrm{R}\,d}{6\,\delta}}\ \text{hyp. log.}\ \sqrt{\frac{w-\mathrm{P}\sqrt{\frac{6\,\delta}{\mathrm{R}\,d}}}{w+\mathrm{P}\sqrt{\frac{6\,\delta}{\mathrm{R}\,d}}}} \qquad (26)$$

the abscissa to the point of the curve where the tangent is parallel to x, and is $-\infty$, or, since u is finite, the curve has an asymptote whenever $w=\mathrm{P}\sqrt{\frac{6\,\delta}{\mathrm{R}d}}$, when $w<\mathrm{P}\sqrt{\frac{6\,\delta}{\mathrm{R}d}}$, there is no asymptote nor parallel tangent; but when $w>\mathrm{P}\sqrt{\frac{6\,\delta}{\mathrm{R}d}}$, the tangent is parallel at a finite negative distance, and for $\mathrm{P}=o$, the tangent is parallel at the origin.

Equation (25) gives the value of u for locating the asymptotes, being always negative except when w and P are zero, in which u is zero, or the axis X an asymptote.

Fig. 1 gives a pictorial representation of the beam with its asymptotes. The

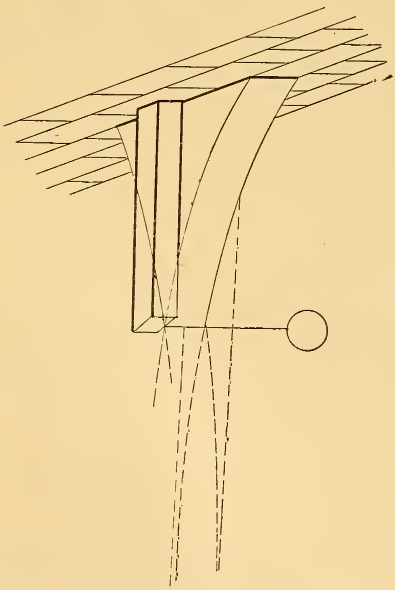


Fig. 1.

curve and beam may extend to infinity in the positive direction of x, where its tangent is perpendicular to X.

2d. Let $w=o$. Then

$$x=\sqrt{\frac{\mathrm{R}\,d}{6\,\delta}}\ \text{hyp. log.}\left(\frac{u}{\mathrm{P}}\sqrt{\frac{\mathrm{R}\delta d^3}{6}}+\sqrt{1+\frac{u^2}{\mathrm{P}^2}\cdot\frac{\mathrm{R}\delta d^3}{6}}\right) \qquad (27)$$

The same as equation (4) obtained by itself. Also,

$$\text{tang. } i=\frac{6\,\mathrm{P}}{\mathrm{R}\,d^2}\sqrt{1+\frac{\mathrm{R}\delta u^2 d^3}{6\mathrm{P}^2}} \quad . \quad (28)$$

and the beam is concave on its sides but less so than in Fig. 1, for eq. (23), the sides meeting at the end with the same angle as in Fig. 1.

As (27) admits of no negative values of x, for u positive or negative, the curve must always end at the point of the beam, and there are no asymptotes.

The beam may be extended in the positive direction to infinity where the tangent line is perpendicular to X, and hence the beam is similar in form to Fig. 1, differing by being more slender and longer for a given breadth.

3d. Let $\mathrm{P}=o$ but w present.

We easily obtain from (23) and (24) the characteristics of the beam. It is concave on its sides, may extend to infinity in the positive direction where the tangent line is perpendicular to X, and is cusped at the free end.

3d. Let both w and $\mathrm{P}=o$.

This is the same case as considered in Professor Wood's *Materials*, Page 193, under "b", where the constants are left undetermined. The reason for these giving the expression the negative sign does not appear.

Equation next preceeding (23), for w and $\mathrm{P}=o$, and for $u=1$ when $x=o$, gives

$$x=\sqrt{\frac{\mathrm{R}\,d}{6\,\delta}}\ \log.\ u$$

Either this, or (24), gives

$$u\ \cot.\ i=\sqrt{\frac{\mathrm{R}\,d}{6\,\delta}},$$

which indicates that the subtangent to this curve has a constant value, and equals the radical in the above equations.

As the subnormal is constant in the common parabola it follows that this curve cuts normally all con-axial parabolas distributed along X, whose parameters are $P=\sqrt{\frac{Rd}{6\delta}}$. This property enables us to readily draw the outline of the beam.

The beam is therefore concave on its sides, and resembles Fig. 1, except that it extends to infinity, X being an asymptote as previously pointed out.

Case II. Let the breadth be constant.

Then $k=by$, $ky=by^2$, $d(ky)=2bydy$

$$\int_o^{ky} kd(ky)=\tfrac{2}{3}\,b^2y^3$$

Ist equation (13) becomes

$$x=\sqrt{\frac{R}{12}}\int\frac{2\,bydy}{\sqrt{\frac{3P^2}{R}}+wby^2+\frac{2}{3}\,\delta b^2y^3} \quad . \quad (29)$$

an expression only integrable in form of a series, except when P or δ are zero; and hence, the curve is not of known form.

Equation (12) reduces to

$$\frac{dy}{dx}=\text{tang. } i=\frac{1}{2by}$$

$$\sqrt{\frac{12}{R}}\sqrt{\frac{3P^2}{R}+wby^2+\frac{2}{3}\,\delta b^2y^3} \quad . \quad (30)$$

When $y=o$ tang. $i=\infty$, and hence the beam is rounded at the end. Multiplying through by y, and we obtain an expression for the subnormal, which is found to increase in some manner with y. In the parabola the subnormal is constant, while in the straight line it is proportional to y. Hence the curve lies between a parabola and straight line, of some values of l and d, and resembles the former.

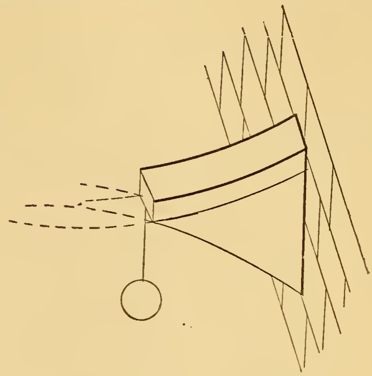
2d. Let $w=o$. We are still unable to find x in convenient terms; but the subnormal increases with y, though less rapidly than before, and hence the curve lies between the previous one and the parabola.

3d. Let $P=o$, but w present. Then (29) reduces to

$$x=\sqrt{\frac{2R}{\delta}}\left(\sqrt{\frac{3\,w}{2\delta b}}+y=\sqrt{\frac{3\,w}{2\delta b}}\right), \quad . \quad (31)$$

the equation of a parabola whose parameter, p, is $\frac{R}{\delta}$; and with principal axis perpendicular to X. The vertex is at a point whose co-ordinates are $-\sqrt{\frac{3Rw}{\delta^2 b}}$ and $-\frac{3\,w}{2\,\delta b}$ for X and Y respectively, and the form of the beam is shown in the Figure.

FIG. 2.



4th. Let w and $P=o$. Eq. (31) then reduces to

$$x^2=\frac{2R}{\delta}\,y \quad . \quad . \quad . \quad (32)$$

a parabola, and the same equation and figure as given for this case in Professor Wood's *Materials*, p. 193.

Case III. Let the cross sections of beam be rectangular and similar. For this, (13) is never integrable in finite terms except when w and P are zero, and then

$$x^2=\frac{5R}{\delta}\,y \quad . \quad . \quad . \quad (33)$$

a parabola.

As the relation of the moment of resistance of beams of rectangular and circular sections are as 1 to $\frac{3}{2}$, the depth in the former being equal to radius in latter, equation (33) becomes, for circular sections

$$x^2=\frac{15}{2}\frac{R}{\delta}\,y$$

the same as given for this case in Wood's *Materials*, p. 194.

NEXT LET THE BEAM BE SUPPORTED AT BOTH ENDS.

Case IV. Let the depth be constant.

1st. Take the loading w per foot, 2 P at the middle, and the beam itself

$k=ud \quad ky=ud^2 \quad d(ky)=d^2\,du$

$$\int kd(ky)=d^3\,\frac{u^2}{2}.$$

These introduced in equation (22), observing that for $x=ou=o$, reduce it to

$$x=\sqrt{\frac{Rd}{6\delta}}\left(\text{arc. sin. } \frac{\delta u d^2+wd}{\sqrt{2C\delta d+w^2d^2}}\right.$$

$$\left.-\text{arc. sin. } \frac{w\,d}{\sqrt{2C\delta d+w^2d^2}}\right) \quad (34)$$

in which

$$C=\frac{3P^2}{R}+wbd^2+\frac{\delta d^3b^2}{2},$$

b and d being the breadth and depth at middle of beam.

It may be remarked that the negative signs under the radical require for this a different formula for integration than that used for Case I, though the exponents are the same. See *Redtenbacher Resultats* 2d. French Ed. p. 492.

The curve is that of a sinusoid, more or less elongated or stretched out in the direction of the axis, according to the coefficient $\sqrt{\frac{Rd}{6\delta}}$.

The point of deflection is to be found where

$$\frac{d^2u}{dx^2}=o.$$

This, see equation (18) gives

$$u=-\frac{w}{\delta d}$$

for the ordinate of the point. This in (34) makes the first term in the brackets zero and gives a negative value for the abscissa X. Thus the position of the point of inflection becomes known, and is in a negative direction on both axes.

Again if we make tang. $i=o$ we find x greater than $\frac{l}{2}$, so that the sides meet at an angle in the middle, and the form of beam is shown in Fig. 3, in horizontal projection.

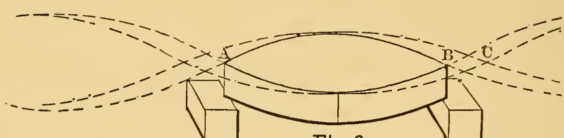


Fig. 3

2d. Let $w=o$. Then

$$x=\sqrt{\frac{Rd}{6\delta}}\text{ arc. sin. } \frac{u}{\sqrt{\frac{6\,P^2}{R\delta d^3}+b^2}}$$

an extended sinusoid, with the point of inflection at the origin.

By means of the equation for tang. i, we find that the sides of the beam meet at the middle with the same angle as before, while at the end the angle of junction is less than before, and the form of beam though more slender, is similar to Fig. 3, A and B being points of inflection in the curves.

3d. If P$=o$ and w present the side of beam will consist of one continuous sinusoid, with position of point of inflection negative on both axes.

4th. Let P and W $=o$, the beam being the only load. Then

$$x=\sqrt{\frac{Rd}{6\delta}}\text{ arc. sin. } \frac{u}{b},$$

and tang. $i=\sqrt{\frac{6\delta}{Rd}}\sqrt{b^2-u^2}.$

Hence the beam is an elongated sinusoid with continuous sides, and the point of inflection at the origin, one side of beam taking just the whole branch of curve.

Observing that $x=\frac{l}{2}$ for $u=b$ we find

$$l=\pi\sqrt{\frac{Rd}{6\delta}}.$$

The form of beam is shown in Fig. 4.

Case V. Let the breadth be constant. Then

$$x=\sqrt{\frac{R}{12}}\int\frac{2bydy}{\sqrt{C-wby^2-\frac{2}{3}\,\delta b^2y^3}} \quad . \quad . \quad (35)$$

only integrable for $\delta=o$, observing that $c=o$ requires $\delta=o$, and hence the curves are not of known form.

If, for instance, δ and P$=o$, the equation reduces to

$$x=\sqrt{\frac{Rb}{3w}}\,(d-\sqrt{d^2-y^2})$$

which, by observing that for $y=d, x=\frac{l}{2}$, reduces to

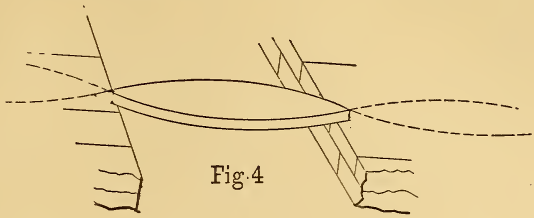


Fig. 4

$$\frac{w}{2}(lx-x^2)=\frac{R}{6}by^2,$$

an ellipse, and the same equation as given for this example in Wood's *Materials*, p. 195.

To gain some knowledge of the form of the beam for equation (35), we obtain, for the subnormal

$$y\frac{dy}{dx}$$

$$=\sqrt{\frac{3}{Rb^2}}\sqrt{\frac{3P^2}{R}+wb(d^2-y^2)+\tfrac{2}{3}\delta b^2(d^3-y^3)} \quad (36)$$

The maximum for this is for $y=o$, or for the end of beam. At the middle it is $\frac{3P}{Rb}$. In the ellipse the subnormal decreases in value from the end, to zero at middle of major axis, while in the parabola it is constant. The above subnormal at middle of beam is usually very small and between those of the two conics named, but at the end we are not able thus to compare. A beam without weight, with load w, only we have seen is elliptical, while with load P, only at middle, it is known to be parabolic.

By making the beam itself part of load, the greatest intensity of this will be at middle, though extended throughout. This tends to place the form of beam between the two conics, whether P, or w, or both, are present.

It would appear therefore that the form of beam, equation (35), lies between the parabola and ellipse, being nearest elliptical when P is absent, and nearest to parabola when w is absent. Equation (36) shows that the beam always has rounded ends, whether any one or all the three forms of load are present.

Case VI. Let the sections be similar rectangles. For this, eq. (22) is not integrable except for $\delta=o$.

The desired curves, therefore, cannot be classified, though some knowledge of them may be obtained by interpretation, similarly as in the last example above.

THE SUPPLY OF AIR TO FURNACES.

From "The Engineer."

To effect the complete combustion of one pound of good Welsh coal 12 lbs. of air are sufficient in theory. That is to say, 12 lbs. of air contain sufficient oxygen to effect the complete combustion of 1 lb. of coal. In practice, however, a much greater quantity of air than this is necessary, because it is impossible to bring all the oxygen in 12 lbs. of air into intimate contact with a pound of burning fuel, and it is usually estimated that from 18 lbs. to 24 lbs. are actually required in practice. It is to be regretted that very few experiments have been made to test this point practically. Such data as we do possess, however, go to confirm the accuracy of the preceding figures. It is well known that the admission of too much air to a furnace reduces the production of steam, and is otherwise uneconomical; but we have reason for stating that it is not generally known why it is prejudicial to admit too much air. When a fire-door is opened the draught is spoiled for the time, and the production of steam is lessened because the quantity of coal burned in any given time is reduced. But besides this, in popular language the flues and boiler are said to be cooled down by the influx of air which has not been raised in temperature by passing through the fire-bars. All this is well enough and sound enough as far as it goes; but it does not go nearly far enough, and we propose here to explain very briefly one aspect of the case which is continually overlooked. Every steam boiler with its furnace is not only a water heating apparatus, but an air heating apparatus as well, and the more heat we expend in raising the temperature of air the less we shall have for the generation of steam. The exact proportions of the heat given out by the combustion of a pound of coal, which goes to the water and is wasted in raising the temperature of air, admits of precise determination. A pound of good coal will, during its perfect combustion, give off 14,500 units of heat—that is to say, as much heat as would raise 1 lb. of water 14,500 deg., or 14,500 lbs. of water 1 deg. In some cases coal gives out more heat than this because of the hydrogen which it contains, in some cases less; 14,500 may be taken as a fair mean. Now, a pound of steam at 75 lbs. absolute pressure contains 1,176 units of heat—that is to say, if we take 1 lb. of water at 32 deg. and boil it and evaporate it under an absolute pressure of 75 lbs. on the square inch, we must expend 1,176 units of heat. As a pound of coal gives out 14,500 units, it follows that a pound of coal can convert into steam $\frac{14,500}{1,176} = 12.33$ lbs., and this is the maximum possible evaporation under the conditions. Of course, if the feed-water is heated the evaporation will be greater. Thus, if the fuel reached a temperature of 212 deg., then the number of additional units of heat required to convert a pound of water into steam would be only 996 instead of 1,176, and $\frac{14,500}{996} = 14.55$ lbs. as the maximum possible evaporation. When we hear of boilers which evaporate 15 lbs. and 16 lbs. of water per pound of coal, we know that the statements made concerning them are simply untrue. But it is not so generally understood that an evaporation of anything like even 14 lbs. is almost impossible of attainment, for the reason which we have already given —namely, that the furnace is an air heater as well as a water heater.

Let us for the moment suppose that a boiler is so well clothed that the loss of heat by radiation may be neglected, and the temperature of the escaping products of combustion, *as they leave the boiler*, is 500 deg. It is not easy to get them less than this with 75 lbs. steam, the sensible temperature of which is 307 deg. Let the consumption of air be the lowest possible—say 20 lbs. per pound of coal burned. The specific heat of air is .238, that of water being 1. That is to say, to heat a pound of air through a certain number of degrees will require only .238 times as much heat as would be needed to raise a pound of water through the same number of degrees. Let us suppose that the temperature of our 20 lbs, of air is 50 deg. In the furnace it will probably be raised to 2,000 deg. or 2,500 deg.; but with this we have nothing to do, because in the flues it gives up, to a considerable extent, to the water in the boiler the heat it received in the furnace. What we have to deal with are the temperatures of the air going into the furnace and leaving the flue. These we have assumed to be 50 deg. and 500 deg. respectively, consequently our 20 lbs. of air has been raised through 450 deg., and to effect this 20×450 deg. $\times .238 = 2,142$ units of heat must be expended; and as these are carried up the chimney they are totally lost. But 2,142 units would suffice for the evaporation of 2.15 of water, the feed being heated to 212 deg., and this must be deducted from the rate of evaporation, based on the assumption that nothing is wasted up the chimney. Consequently $14.56 - 2.15 = 12.41$ lbs. may be taken as the maximum possible evaporation to be had under the conditions. There are certain boilers in use, however, in which the heat of the escaping products of combustion is not more than 50 deg. greater than that of the steam; and with such boilers, and with some of the Welsh coals which contain as much as 15,300 heat units per 1 lb., an evaporation of 12.5 lbs. of water may be reached in practice. Results apparently greater than this have been attained, but they must be attributed either to priming which raised the consumption of feed-water; or to the use of feed-water heated to a temperature even greater than that in the boiler, as not unfrequently happens when good "economizers" are used. We have said enough, we think, to show that it is highly desirable that the consumption of air per pound of fuel should be made as small as possible.

If any apology were needed for placing before our readers a statement of truths with which every engineer should be familiar, it would be found in the circumstance that we have recently received a circular which is now being issued by the inventor and patentee of a well-known, and we may add excellent, fire-door, intended to prevent the production of smoke. This circular sets forth particulars of a trial conducted at Messrs. Hanley's Telegraph Works, with two Lancashire boilers, one fitted with the fire doors, to which we have just referred, the other having ordinary doors. The trials seem to have been carefully conducted, with the result that the boiler with the patent door evaporated 11.44 lbs. of water per pound of coal, while the ordinary boiler evaporated but 9 lbs. We would pass this statement over in silence, because it does not contain any strong improbability, although we doubt that any fire-door or smoke consuming appliances in existence possesses so much merit. But we cannot pass over what follows. It appears that to make the data complete, the author of the circular under notice used a patent anemometer to measure the quantity of air admitted to the furnace, by which it was ascertained that with the patent fire-doors 491.4 cubic feet of air were used per pound of coal, while the ordinary boiler used 196.6 cubic feet only. Taking the temperature of the air in the boiler room as between 60 deg. and 70 deg., we shall not be far wrong if we assume that 14 cubic feet of air weighed 1 lb. Thus the consumption of air with the patent door was $\frac{491.4}{14} = 35.1$ lbs. per lb. of coal. The temperature of the products of combustion leaving the flues is not stated, but it could not have been much under 600 deg., judging from our experience of Lancashire boilers. We shall be on the safe side if we estimate that each pound of the 35 lbs. of air admitted to the furnace carried away 500 heat units with it. Then $35 \times 500 \times .238 = 4{,}165$ as the total loss of heat, but $\frac{4{,}165}{996} = 4.18$ lbs. of water if the feed had been heated to 212 deg. As this is improbable, however, we shall say that enough heat went up the chimney per lb. of coal burned to evaporate 3.75 lbs. of water. Now, we are told that the actual evaporation was 11.44 lbs. Adding to this the 3.75 lbs., we have as the total heat in each pound of coal enough to evaporate 15.19 lbs. of water from 100 deg. to 50 lbs. or 60 lbs. steam, and this without leaving anything for loss by radiation or conduction. We have just endeavored to show that such a result is physically impossible of attainment. It remains for the gentleman who has issued the circular to the confiding steam users of the kingdom to explain the inconsistency. Either his anemometer deceives him, or his feed-water measuring arrangements were at fault.

Turning to the boiler without the patent fire-door, we find it stated that while the evaporation was 9 lbs. of water per pound of coal, the consumption of air was 198.6 cubic feet, or, in round numbers, 14 lbs. per pound of coal. It is barely possible that complete combustion could be effected with so small an admission of air; and the probability is that the boiler smoked a good deal. But the quantity of heat carried off in the air could not have exceeded 1,666 units per pound of coal, or say the equivalent of 1.5 lbs. of water evaporated. If we add this to 9 lbs. we have 10.5 as the value of the coal, and allowing for loss by radiation, it would appear that this boiler was not worked to much disadvantage. It would probably have done better with more air. But, as we have shown, an admission of 35 lbs. per pound of coal would have represented the absolute loss of 3.75 lbs. of steam per pound of coal; that is to say, before any advantage could be gained from the extra admission of air the coal must give out per pound, heat equivalent to 9 lbs. + 3.75 lbs. of water converted into steam; but, inasmuch as the coal could not do this, we fail to see how any advantage could possibly be gained.

The lesson taught by the circular we have criticised is that a great deal has yet to be learned by men who undertake to improve the performance of steam machinery. As we have said already, we believe that the fire-door concerning which the circular has been issued is a very good and simple appliance; and we feel perfectly certain that the writer of the circular had no intention of deceiving the public. If he had been better informed, he would have stopped to think how such and such things could be before he rushed into print. As the matter stands, we can hardly sufficiently admire the exquisite *naiveté* of an inventor who can boast that he uses more air per pound of coal than other men. There is reason to believe that he does not yet understand that the real merit of his invention lies in its great simplicity, and the efficiency with which it supplies a portion of the air requisite for combustion exactly in the right place and in the right way. If he works his apparatus in such a fashion that he admits 35 lbs. of air per pound of coal, then he is doing his invention a grave injustice, and proving very clearly that, whatever else he may be, he is not a competent stoker.

ON THE CURRENTS IN NAVIGABLE RIVERS.

By A. RULLIER.

From "Revue Maritime et Coloniale."

Rivers in their flow tend to wash the materials of their banks into the bed of the stream. When the current is gentle, the silt and clay in the banks are deposited in the center, and the sandy portions at the sides; the bed of the river is gradually raised, and the width increased. When the current is rapid the banks are undermined, the lighter particles are carried away, and the heavier portions remain at the sides impeding the undermining action, and the bed of the river is deepened: this action continues till the current slackens, when the banks again gradually resume their original slopes. The navigation of the straight reaches of a river presents no difficulty; the greatest depth is in general in the middle, and large vessels always follow the center of the stream, but vessels of small draught when ascending the river hug one of the banks, as the force of the current is less at the sides than in the center. When the river is shoal on one side the current is diverted towards the opposite bank, which assumes a perpendicular face, indicating thereby the existence of a shoal on the farther side. When banks are formed in a river whose course is straight, they usually are found in the center, of an oval shape in plan, and triangular in longitudinal section; their presence, when below water, is manifested by the deviation of the current and by the ripples they give rise to, behind which the water is smooth. Occasionally the channels on either side of the bank are equally suitable for navigation, but more frequently one channel deepens at the expense of the other, and this is indicated by the steepness of the banks of the deeper channel. When the river takes a bend the direction of the current does not at once follow the altered line of the banks, but approaches the concave bank, and brings the greatest velocity and the greatest depth of the river near that bank. The concave bank is gradually encroached upon, and a deposit is formed near the opposite bank, and the river frequently increases in breadth at the bend. On account of the direction the current takes at a bend, vessels ascending the river hug the convex bank, and, when descending, keep near the concave bank. If the bend is very sharp, the stream is directed with considerable impetus against the concave bank, and, washing away the bank and scouring the bed, strikes across the river towards the opposite bank; silting takes place at the convex bank, which becomes pointed and has a gentle slope, whilst the concave bank is vertical. When the course of the stream is a curve of small radius, the river has generally a small breadth in proportion to the amount of its discharge; the strength of the current merely approaches the concave bank, and banks are rarely formed in the bed of the stream. When the river curves gently and runs through a loose soil it increases in breadth, diminishes in depth, and banks are frequently formed in the middle.

Through narrow passes the depth of a river is usually considerable, and its flow rapid; in these places vessels are always obliged to keep to the center of the river so as to avoid the whirlpools and back currents caused by projections from the banks. A tributary flowing into a straight reach of a river leads to the formation of a bank, where the current of the tributary is checked by impinging upon the main stream, and, other conditions remaining the same, the size of the bank is proportional to the angle of inclination between the two streams. The best channel for vessels is generally on the side where the tributary flows in, except when the latter is very small. When the junction of the tributary occurs at a bend in the river on the concave side, the bed is scoured on that side; and a deposite is formed at the point where the bank and the tributary unite, the convex bank is little affected by the confluence of the two streams. If the mouth of the tributary is on the convex side of a bend in the main river, the tributary, finding little resistance at its mouth, on account of the sluggishness of the river round the convex bank, continues its course for some distance across the main stream till it gradually merges into it, turning the direction of the current, when the tributary is strong, still more against the concave bank and increasing the encroachment on that side. When the main stream takes a sharp bend and the tributary flows in on the concave side, the result is very similar to the case just considered. A tributary flowing in where the river is curving gently, and above the part where banks tend to form, renders the navigation very complicated, as a bar is formed which sometimes extends so as to unite with the banks in the river. The navigable channel is almost always situated close to the mouth of the tributary, gradually tending towards the center of the river.

When the junction occurs where the river is obstructed by banks, the waters of the tributary assist in opening a passage through the banks and improving the navigable channel.

The Author explains at some length the proper measures to be adopted, in river navigation, in casting and weighing anchor, and the course that should be followed by a vessel going up or down a river in the various cases mentioned above.

STEAM INJECTORS.

Translated from the French of M. LEON POCHET.

I.

GENERAL THEORY OF STEAM INJECTORS.

It is some years since M. Giffard introduced the injector apparatus which bears his name and which filled the scientific world with profound astonishment.

This ingenious apparatus, in which a jet of steam heading out of a boiler enters into the same boiler bringing with it a quantity of additional water, seems to proceed in accordance with a philosophical law contradictory to the ordinary laws of physics. It was in appearance a sort of perpetual motion. If the mechanical properties of heat had been better known, nothing would have appeared more simple.

M. Reech, published, in 1858, (in the memorial du Genie Maritime), a theory founded upon laws of the old philosophy, which gives a good account of the functions of the Giffard injector.

The new theory which we proceed to give—of the Giffard injector in particular, and of steam injectors in general—rests upon the mechanical theory of heat. It seems the more important inasmuch as injectors are now applied to such a great variety of purposes.

We will describe first the action of an

injector. A tube terminating in a conical pipe A, Fig. 1 discharges a jet of steam which comes from the boiler. This tube opens into a chamber B B which communicates with a reservoir of cold water RR by a vertical tube CC. It is this water which is introduced into the boiler.

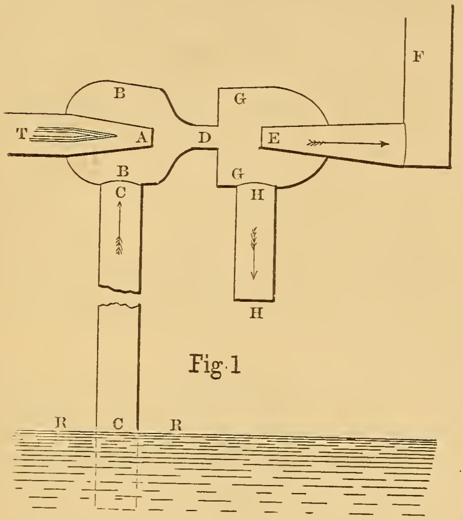


Fig. 1

Under the action of the jet of steam the air in the chamber B is rarefied and the rarefaction results in the atmospheric pressure raising the water of the reservoir in the tube C. As soon as the cold water comes in contact with the steam in the chamber B a portion of the steam is condensed and the apparatus is so regulated that this condensation is complete. Then we have, merely, a jet of liquid to pass on through the contracted section D and be introduced into the conical, diverging tube which communicates with the boiler. The tube EE is nothing more than a Venturi tube.

In such a tube, water introduced with a certain velocity V would be able to overcome the pressure due to the height $\frac{V^2}{2g}$, provided that the liquid column be uninterrupted and the widening be progressive; or if we call ω the section of the tube at its origin, and ω' the section of the same tube at its entrance into the boiler, H the height of water corresponding to the effective pressure of the boiler, that is to say its absolute pressure diminished by one atmosphere, we shall have

$$\frac{V^2}{2g}\left(1-\frac{\omega^2}{\omega'^2}\right)=H.$$

In the Giffard injector we make

$$\frac{\omega}{\omega'}=0,16.$$

whence

$$\frac{\omega^2}{\omega'^2}=0,0256,$$

consequently

$$\frac{V^2}{2g}\times 0,9744=H.$$

But we should be able to give to the ratio $\frac{\omega}{\omega'}$ greater value, and we can always assume approximately:

$$\frac{V^2}{2g}=H.$$

The condition that the liquid jet, through the tube E E, is uninterrupted assumes that the jet is at too low a temperature to be transformed into steam at the atmospheric pressure in its passage through the chamber G G. Hence its temperature should be below 100°.

Should the temperature exceed 100° the working of the apparatus is imperfect. We are warned by a production of steam which fills up the chamber G G and which escapes by the discharge pipe H H.

Then we should remove the pipe A of the contracted orifice D in order to increase the useful section of this orifice, or, we should lessen the quantity of steam of the jet by diminishing the orifice A by the conical rod T. Thus the conditions of the proper working of the apparatus are:

1st. That all of the jet of steam A be condensed by affluent water;

2d. That the temperature of the mixture be lower than the temperature of corresponding saturation at the mean pressure of G.

In case that the chamber G communicates with the atmosphere, the temperature of corresponding saturation is 100°. But it might happen that there be any pressure in the chamber G. It may be higher or lower than the atmospheric pressure. We will make no special hypothesis upon its value.

Call t_0 the temperature of the boiler; t the temperature of the jet of steam at the moment that it fills the chamber BB. This temperature will be the temperature of saturation corresponding to the mean pressure. It is easy to see that this pressure equals the atmospheric pressure diminished by the height of the column of water CC, if the feeding reservoir RR is lower, and augmented by this height if it is higher.

τ, the temperature of the liquid jet at the moment that it enters the divergent tube EE. This temperature is lower than 100° when the chamber GG communicates with the atmosphere, which is the case in the Giffard injectors;

θ, the temperature of the water in the reservoir RR.

Suppose one kilogramme of saturated steam issuing from the pipe A and containing a proportion x of steam.

Let y be the weight of water which the kilogramme of steam raises and conveys from the reservoir RR.

Let w be the velocity of the steam jet in A;

V the velocity of the mixture at the entrance of the tube E. To solve the problem we will write two equations.

1st. We assume that since there is no heat lost or gained by the material of the apparatus, the sum of internal heat augmented by the calorific equivalent of the living force has not changed during the phenomena; for this heat should always appear under the form of heat, or under the form of living force. This is in accordance with the theorem of living force developed by the theory of heat.

2d. The theorem of rational mechanics relating to momentum is here applicable as it always is whatever the exchange of heat may be, for in the equation of this theorem the interior forces disappear. The amount of internal heat above 0° in a kilogramme of steam of the jet A is:

$$\int_0^t ldt + (r - Apu)x.*$$

The calorific equivalent of the living force has for value $\frac{Aw^2}{2g}$.

The total quantity of heat is

$$\frac{Aw^2}{2g} + \int_0^t ldt + (r - Apu)x.$$

The internal heat of the affluent water is

$$y\int_0^\theta ldt.$$

The living force is almost nothing and may be neglected; the internal heat augmented by the calorific equivalent of the living force before the mixture, will be then

$$\frac{Aw^2}{2g} + \int_0^t ldt + (r - Apu)x + y\int_0^\theta ldt.$$

The mixture forms, the steam is completely condensed, there is a diminution of volume and production of negative mechanical work. The total internal heat is augmented by the calorific equivalent of the work corresponding to the condensation, and which is

$$Apux.$$

When the mixture passes through the contracted section D, the sum of the living force and of the internal heat is

$$\frac{Aw^2}{2g} + \int_0^t ldt + rx + y\int_0^\theta ldt \quad . \quad . \quad (A).$$

The introduction commences in the tube EE, the total weight of the mixture

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* The internal heat of any humid vapor, that is, part liquid and part vapor, is determined as follows:

Let x=the weight of the vapor in a kilogramme of the mixture.

Then $1-x$ the weight of the water in a kilogramme of the mixture.

Then the excess of internal heat of the vapor at t^0 compared with water at 0^0 is,

$$(r + L - Apu)x.$$

In this expression,

L is the quantity of heat required to raise a kilogramme of the liquid from 0^0 to t^0 when in contact with its vapor.

A is the reciprocal of the Mechanical Equivalent of heat or $\frac{1}{424}$.

p is the pressure.

r is the latent heat of the vapor,

u is the excess of volume of the vapor over the liquid which yielded it.

pu is therefore our expression for work;

And Apu is its heat equivalent.

Now, as the latnet heat liquid in the vapor is L $(1-x)$, the total internal heat,

$$Q = L(1-x) + (r + L - Apu)x.$$
$$= L + (r - Apu)x.$$

Or if l is the specific heat of the liquid at the temperature $t°$, then

$$L = \int_0^t ldt$$

$$Q = \int_0^t ldt + (r - Apu)x.$$

is $(1+y)$, its internal heat, since it is entirely in a liquid state, is expressed by

$$(1+y)\int_0^t ldt,$$

And its living force is,

$$(1+y)\frac{AV^2}{2g},$$

since V is the common velocity.

The sum of internal heat above O, and of the calorific equivalent of the living force at the inlet of the tube EE, is therefore

$$(1+y)\left(\int_0^\tau ldt+\frac{AV^2}{2g}\right)$$

This new expression of the total heat should be equal to the expression in (A). We have the equation

$$\frac{Aw^2}{2g}+\int_0^t ldt+rx+y\int_0^\theta ldt=(1+y)$$
$$\left(\int_0^\tau ldt+\frac{AV^2}{2g}\right) \quad . \quad . \quad \text{(B)}$$

Now in consequence of the fundamental formula for the cooling of vapors, we have

$$\frac{Aw^2}{2g}=\int_t^{t_0} ldt+r_0x_0-rx,\text{*}$$

Substituting this value in the preceding equations it gives, after some transformations,

$$\int_\theta^{t_0} ldt+r_0x_0=(1+y)\left(\int_\theta^\tau ldt+\frac{AV^2}{2g}\right)\text{(C)}$$

This is the equation of living force. We will now establish the equations of momentum. We shall have them due to the contracted section D,

$$\omega V,$$

for this section is necessarily equal to that of the inlet of the tube EE and the weight of water has for its value

$$1000\omega V.$$

Its mass is

$$\frac{1000\omega V}{g}$$

In short, the expression for momentum is

$$\frac{1000\omega V}{g}V=\frac{1000\omega V^2}{g}$$

The amount of work of the affluent water from the reservoir RR may be neglected. As for the steam jet A, the amount delivered per second is evidently equal to that of the final mixture divided by $(1+y)$, and its velocity is w and its quantity of work is therefore, before its passage into section D

$$\frac{1000\omega}{g}V\frac{w}{1+y}.$$

and we find also for the increase of the momentum during a second from one side to the other of the contracted section D

$$\frac{1000\omega}{g}V\left(V-\frac{w}{1+y}\right)$$

Let us call π the pressure per square meter in the chamber GG, which is equal to the atmospheric pressure in the Giffard injectors, and P the pressure in the chamber BB which is equal to the atmospheric pressure diminished or increased by the column of water CC according as the supply reservoir RR is below or above the apparatus.

The contracted section D separates the jet into two parts, that above being subjected to the pressure P, and that below to the pressure π. The impulse of exterior forces during the exchange of velocities will be, per second

$$(P-\pi)\omega,$$

We have then, in accordance with the principle of equality of moments

$$\frac{1000\omega}{g}V\left(V-\frac{w}{1+y}\right)=(P-\pi)\omega,$$

Whence

$$V\left(V-\frac{w}{(1+y)}\right)=\frac{(P-\pi)g}{1000}. \quad . \quad . \quad . \quad \text{(D)}$$

The two equations (C) and (D) include the theory of steam injectors.—I copy here:

$$\int_\theta^{t_0} ldt+r_0x_0=(1+y)\left(\int_\theta^\tau ldt+\frac{AV^2}{2g}\right), \quad \text{(C)}$$

$$V\left(V-\frac{w}{1+y}\right)=\frac{(P-\pi)g}{1000}. \quad . \quad . \quad . \quad . \quad \text{(D)}$$

GIFFARD INJECTORS FOR FEEDING BOILERS.

In the Giffard injector (Fig. 1) the reservoir R R is ordinarily near the chamber B B, the pressure P is nearly equal to the atmospheric pressure, and as the chamber G G is in communication with the atmosphere,—we can take

* r_0 and r designating the quantities of heat of vaporization at the temperatures t_0 and t.

$$P=\pi,$$

and we ought to have

$$\tau<100^\circ.$$

Equation (D) of the moments reduces to

$$V-\frac{w}{1+y}=0,$$

whence

$$V=\frac{w}{1+y}.$$

Take now the equation (C). In the second member of that equation we may neglect the term $\frac{AV^2}{2g}$

In effect the range of temperature τ and θ is always large enough. The following table demonstrates that V varies almost precisely as the difference $(\tau-\theta)$:

The equation (C) gives then approximately,

$$1+y=\frac{\int_{\theta}^{t_0} ldt+r_0x_0-\theta}{\tau-\theta} \quad . \quad \text{(E)}$$

Under this form we observe that y diminishes as τ increases. The minimum of y corresponds then with the maximum of τ, that is to say, at 100°.

We see also that y increases when θ increases; that is to say, in proportion to the heat of the feed water.

y increases in the same proportion that the temperatures τ and θ approach each other in value. Consequently when $\theta=100°$ y is infinite.

Experience demonstrates that the action of the injector ceases before reaching this limit, at about 70°.

WEIGHT OF WATER RAISED AND VELOCITY OF MIXTURE IN GIFFARD INJECTOR FOR FEEDING BOILERS.

		PRESSURE OF THE BOILER.							
		5 ATMOSPHERES. (152°,22), $w=714^m$.				3 ATMOSPHERES. (133°,91), $w=596^m$.			
Value of θ	Temperature of the Mixture.	Weight of Water raised per kilogr'm of steam suppos'd to be dry y	Velocity of the Mixture per second. V	Height to which the jet is raised. $\frac{V^2}{2g}$	Mechanical Work produced. $y\frac{V^2}{2g}$	Weight of Water raised per kilogr'm of steam suppos'd to be dry y	Velocity of the Mixture per second. V	Height to which the jet is raised. $\frac{V^2}{2g}$	Mechanical Work produced. $y\frac{V^2}{2g}$
		k.	m.	m.	km.	k.	m.	m.	km.
$\theta=13°$	100	6,35	97,29	482,3	3063	6,29	81,73	340,5	2141
	80	8,55	74,87	285,7	2443	8,47	62,94	201,9	1710
	60	12,61	52,54	140,7	1774	12,50	44,15	99,4	1242
	40	22,70	30,17	46,4	1053	22,50	25,36	32,8	737
	20	90,42	7,82	3,12	282	89,63	6.57	2,21	197
	13	∞	0	0	0	∞	0	0	0
$\theta=50°$	100	11,06	59,29	179,2	1981	10,95	49,88	126,8	1389
	80	19,10	35,57	64,5	1232	18,92	29,95	45,6	864
	60	59,50	11,85	7,17	425	58,74	9,97	5,07	298
	50	∞	0	0	0	∞	0	0	0

We are able then to state the following propositions.

1st. The proportion of conveyed water increases and, consequently, the velocity of the mixture diminishes when the temperature of the water in the supply reservoir is raised.

2d. The proportion of conveyed water increases when the temperature of the mixture dimimishes. It is a minimum when the temperature of the mixture is of 100°. The velocity then attains its maximum.

3d. It diminishes, on the contrary, when the steam is not dry and the proportion of water which it contains increses.

In preceeding page is a table of the values of y and of V for the boiler pressures of five and three atmospheres and the temperatures of 13° and 50° of the feeding water, the steam being dry.

The proportion of water raised increases rapidly as the temperature τ of the mixture diminishes.

The velocity diminishes in nearly the same ratio.

The quantity of water raised corresponding to the boiler pressures five atmospheres and three atmospheres are nearly the same, but the velocities are widely different. If we would have the velocity, and, consequently, the composition of the mixture corresponding to the pressure of the boiler, we must make

$$\frac{V^2}{2g}=\begin{cases}41{,}32 \text{ for five atmospheres,}\\ 20{,}66 \text{ for three atmospheres,}\end{cases}$$

whence

$$V=\begin{cases}28^m{,}50 \text{ for five atmospheres,}\\ 20^m{,}15 \text{ for three atmospheres.}\end{cases}$$

These numbers correspond to

$$y=\begin{cases}24{,}06 \text{ for five atmospheres,}\\ 31{,}02 \text{ for three atmospheres.}\end{cases}$$

The temperature of the mixture is nearly 40° if the temperature of the feed-water is 13°.

ACTION OF THE GIFFARD INJECTOR.

There are two ways of considering the action of the Giffard injector. We measure the mechanical work performed without taking into account the heat carried away by the mixture; or, with taking this heat into account.

Following the last mode of operation, which is the only rational one, when employed in feeding the boiler the injector performs good service. It is clear that, since there is no loss of heat outside, and that the final living force is nothing, all the heat carried away by the steam jet is restored in the mixture, excepting that corresponding to the mechanical work accomplished, $\frac{AV^2}{2g}y$. Equation (C) is the mathematical expression of this fact.

It is not necessary to take into account the friction in the tubes, if we consider them impervious to heat, for the friction produces heat which is not lost by external radiation, but is found in the internal heat of the mixture.

The quantity of heat augmented by the living force in the mixture at the moment of its entrance into the convergent tube counted above, the temperature θ (which is the exterior temperature, and which serves as the starting point for the temperature in the equation (C)) is

$$(1+y)\left(\int_o^\tau ldt+\frac{AV^2}{2g}\right).$$

The portion $(1+y)\frac{AV^2}{2g}$ represents the heat equivalent of the living force of the mixture. This living force in part disappears in the work of introduction into the boiler. If things are so regulated that the height $\frac{V^2}{2g}$ precisely correspond to the relative pressure of the boiler, the living force $(1+y)\ \frac{V^2}{2g}$ is effectually destroyed by the back pressure of the boiler; the introduction into the boiler will have no velocity, and the quantity of heat introduced will be definitely

$$(1+y)\int_\theta^\tau ldt$$

or about

$$(1+y)\ (\tau-\theta).$$

If the velocity V of the mixture is greater than that which corresponds to the relative pressure H, of the boiler, (measured by a column of water) the mixture will posess a certain living force

$$\frac{V^2}{2g}-H,$$

at its entrance into the boiler, but this living force becomes heat, in the motions which it occasions, so that no more heat can disappear than the quantity

$$AH\ (1+y).$$

Thus we know whatever the velocity V of the mixture there will disappear only the quantity of heat corresponding to the work

$$(1+y)\ H,$$

of the introduction into the boiler. This work comprises two terms :

y H and $1 \times$ H.

The first represents the useful work in feeding; the second corresponds in reality to a quantity of heat which ought to be found in the heat of the mixture; this is a loss which is balanced by a previous gain made by the steam at the moment of exit from the boiler.

Suppose, then, that the velocity V of the mixture be precisely that which gives

$$\frac{V^2}{2g}=H,$$

so that the introduction of the mixture into the boiler be made without velocity; determine, by experiment, the quantity of water raised y, its temperature τ^1 and calculate the same temperature by the formula (E). The heat which should be brought back to the boiler, is, theoretically

$$(1+y)\ (\tau-\theta),$$

The heat brought back is, in reality,

$$(1+y)\ (\tau'-\theta).$$

There is then, practically, a loss of heat

$$(1+y)\ (\tau-\tau').$$

Add to this loss the loss of heat resulting from work accomplished

$$\frac{AV^2}{2g}y,$$

We have for total loss

$$(1+y)\ (\tau-\tau')+\frac{AV^2}{2g}y.$$

This waste of heat applied to the introduction of y kilogrammes of water into the boiler, gives for waste of heat per kilogramme:

$$i=\frac{1+y}{y}(\tau-\tau')+\frac{AV^2}{2g} \quad . \quad . \quad (F)$$

Here is an experiment given by M. Reech. M. Giffard succeeded in feeding a boiler at five atmospheres, by conveying a weight of water equal to fifteen times that of the steam. The temperature of the mixture was 48°, the affluent water being 13°. We have then, in this experiment:

$$\theta=13^\circ$$
$$y=15.$$

The formula (E) gives

$$\tau=53^\circ,01.$$

Now then, the experiment indicates

$$\tau=48^\circ.$$

Consequently,

$$\tau-\tau'=5^\circ,01.$$

Now the waste of heat per kilogramme of feed water, is, (equation F):

$$i=\frac{16}{15}\times 5,01+\frac{41,32}{424}$$
$$=5,34+0,097=5.44 \text{ heat units.}$$

This number represents $\frac{1.55}{100}$ of the difference of temperature $(\tau-\theta)$.

This quantity of heat really disappears and is not found again. All other quantities of heat carried out of the boiler by the jet of steam y have been returned by the mixture.

Now, consider an ordinary supply pump, which introduces water into the boiler, at the temperature of 13°. This pump is operated by the engine, and produces useful work,

$$AH,$$

(H=height of water corresponding to the excess of the boiler-pressure over that of the condenser) per kilogramme of feeding-water, but it utilizes only a fraction k of force by reason of the friction or resistances of various kinds.

Now this force is only that of the steam; and we know that ordinary non-condensing steam engines use scarcely three parts in 100 of the heat transmitted to the boiler; then the introduction of a kilogramme of water into the boiler, by means of a feed-pump requires an expense of heat of

$$\frac{1}{0,03}\ \frac{AH}{k}.$$

The co-efficient k of the ordinary pump is 0,50, consequently this quantity of heat has for its value

$$66,\ 6\ AH.$$

Observe that the water introduced is not of the temperature θ of the supply reservoir. To raise the temperature of this water from θ to τ it will be necessary to consume a quantity of heat $(\tau-\theta)$, but as the heating apparatus never uses but $\frac{2}{3}$ of the heat developed by the combustion there will be $\frac{1}{3}$ of the heat lost. The total consumption of heat will be then,

$$j=66,\ 6\ AH+\tfrac{1}{3}\,(\tau-\theta).$$

By feeding by means of an injector, we had found the loss of heat to be,

$$i=0,155\ (\tau-\theta).$$

It is easy to see that the first is the more important. Suppose, for example, a pressure of five atmospheres, we will have:

$$H=41,32,$$
$$\tau=48^{\circ},$$
$$\theta=13^{\circ},$$

$j=18.20$ heat units, $i=5.44$ heat units.

In this case, the cost of feeding by means of an injector is less than one-third of that of feeding by means of a pump.

These results would be somewhat modified if we had the use of a good condensing engine. Here the work of the engine is 10-100; that of the pump, if well established, 60-100, introducing water from the condenser at a temperature of 50°. The injector should work equally with the water of the condenser. We should always have $y=15$.

The value of τ resulting from equation (E) would be

$$\tau=87^{\circ},\ 70,$$

If we admit that the loss of heat by the injector will be more than 15,5-100 of the difference $\tau-\theta$ we will have for this loss

$$i=0,155\times 37,7=5 \text{ heat units, } 84.$$

The loss of heat from feeding by means of a pump, and of heating the water from 50° to 87°,70, will have for value

$$j=\frac{1}{0,10}\ \frac{\text{AH}}{0,60}+\frac{1}{3}\ (87,70-50)=14.12 \text{ heat units}$$

This is more than double the number 5.84 heat units. The economic advantage is always on the side of the Giffard injector; and this apparatus possesses also a great simplicity in adjustment and working, and an important economy of heat. The injector gains from nine to thirteen *calorics* per kilogramme (heat units) of water introduced into the boiler.

THE GIFFARD INJECTOR EMPLOYED AS A PUMP.

The Giffard injector is a suction and forcing pump, but its mechanical performance is weak, because the greater part of the heat is employed in raising the temperature of the water. The expression of the mechanical rendering per kilogramme of wasted steam, is,

$$y\,\frac{V^2}{2g},$$

and its calorific equivalent

$$y\,\frac{AV}{2g}.$$

We have inserted in the table the values of the product $y\frac{V^2}{2g}$ for the different cases.

We see, by an inspection of the table, that the velocity of the mixture varies from 0 to 97^{m}, 29, that it corresponds to the height of water from 0 to 482 metres. Consequently we are able to introduce water into a reservoir against a pressure of,

$$\frac{482}{10,33}=\text{about 46 atmospheres.}$$

The mechanical work $y\frac{V^2}{2g}$ augments with the velocity. At the temperature 100° of the mixture, there are 3,063 kilogrammetres per kilogramme of wasted steam. If we compare this number with those of the preceding table, we see that it is only one-eighth of the theoretical work of steam in a non-condensing engine. The mechanical work would be only third of that which would be performed by a pump placed in the same conditions for the same purpose.

If we take the numbers corresponding to the temperature of 40° of the mixture, temperature for which $y=22,70$, $V=30,17$; the mechanical work produced is no more than 1,053 kilogrammetres.

It is reduced to the third of that which it was for $\tau=100^{\circ}$.

Considering, in a general manner, the Giffard injector as an exhausting pump, the problem ought to stand thus:

The height to which it is necessary to raise the water being given, what will be the mechanical performance of the injector?

At first sight it is clear that we wish to place the apparatus at the greatest possible height above the reservoir to be drained. In doing this we diminish the pressure in the chamber BB, (Fig. 2). Consequently, we lower the temperature

t of the steam jet, which is nothing more than the temperature of saturation corresponding to the pressure in the reservoir BB. The raising of the water into the chamber BB, will be the same as raising it in a suction pump. We should be able then to raise it to the ordinary

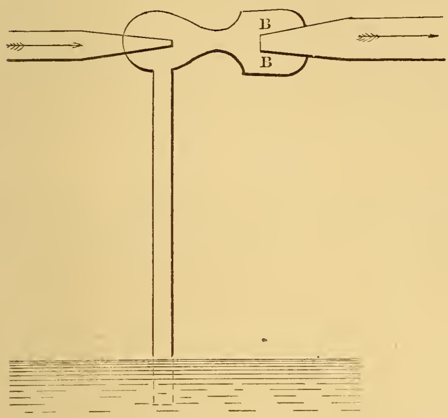


Fig. 2

practical limits, that is to say, eight metres. Under these conditions, there will be the greatest possible fall of the temperature of the steam from the boiler to the orifice of the injector. We shall have the maximum of mechanical effect, and there will be, between an injector working thus, and an ordinary feeding injector, when the steam is at about 100°, the same difference as between a condensing, and a non-condensing steam engine.

The height being eight metres, the pressure in the chamber BB will be

$$10,33-8^{m}=2,33 \text{ of water}$$

or

$$176^{mm} \text{ of mercury.}$$

The temperature of corresponding saturation is about 63°. Going back to equations (D) (E), we will have for determining the minimum of the velocity of the mixture the equation

$$\frac{V^2}{2g}=h.$$

Equation (D) will give us

$$V\left(V-\frac{W}{(1+y)}\right)=-8g,$$

from these two equations we deduce

$$1+y=\frac{Vw}{V^2+8g}=\frac{\sqrt{hw}\over\sqrt{2g}}{h+4.} \qquad \text{(G)}$$

The weight of water raised will be the greater as w will be greater. Now, the initial and final temperatures of the steam, during its flow, being determined, w depends only upon the moisture of the steam. The quantity of water raised will be greater in proportion as the steam is dry.

The mechanical work produced by the apparatus will be

$$\tau=y\ (h+8). \qquad \text{(H)}$$

Here is a table of quantities of water raised by an injector pump placed at eight metres above the exhausting reservoir, and fed by dry steam at five atmospheres:

Total Height of Elevation.	Injection of Dry Steam at 152°,82. Velocity, w=930^{m}.		
	Weight of Water raised per kilogram. of Steam used.	Mechanical Work obtained.	Temperature of Water raised.
h+8	y	W	τ
		km.	
1+8=9	41,0	369	"
10+8=18	46,37	835	"
50+8=58	26,47	1535	"
100+8=108	19,18	2071	"
200+8=208	13,51	2810	"
500+8=508	8,30	4216	"
800+8=808	6,89	5163	100°

This table shows that the mechanical performance of the injector pump increases rapidly with great heights, otherwise it is inferior to ordinary steam pumps. It is then for great elevations that the injector gives most satisfactory results. It would be little economy to employ it in common use, but it would be very useful for draining exceptional leaks in mines, when the ordinary pumps are not sufficient. The extreme simplicity of this kind of apparatus will often give it the preference over others that do more perfect work.

We ought again to remark the importance of placing the injector at the height of eight metres above the reservoir.

Whereas, in the first table we have found a performance of 3,063 kilogrammetres for an elevation of 482 ^{m},3 the injector being at the level of the reservoir; the table above gives us a performance of 4,216 kilogrammetres for a height nearly equal to the former—that is to say, 508 metres.

DRAINING SMALL DEPTHS WITH THE INJECTORS.

Steam injectors are employed at the side of vessels for draining leaks in the hold. Under these circumstances the total height of lifting varies from five to ten metres, and each kilogramme of expended steam furnishes about 900 kilogrammetres. Now, in a ship's engine, one kilogramme of steam produces about 17,000 kilogrammetres, according to M. Freminville's treatise on Marine Engines. A pump in the hold would perform only one fourth of this work, according to that, one kilogramme of steam would produce a useful work of 4,250 kilogrammetres.

Compare the number 900 kilogrammetre with this last, and we shall find the ratio of the work of the steam injector to that of the pump,

$$\frac{900}{4250}=0{,}211.$$

According to M. Freminville, this number should, in practice, be diminished to 0,16.

THE IRON MANUFACTURE OF RUSSIA.

From "Iron."

The importance of the iron trade in modern States is such that their economical condition may be said to be definable by its extent and development. Every State is glad to see this particular manufacture prosperous within its borders, and in various ways favors it. Russia seems to have been attracted by the example of America in endeavoring at the present time to free herself from dependence upon external aid, the need for which has hitherto made itself felt in the supply of the large quantities of iron needed for the permanent way now in construction in Russia. There are two economico-scientific societies in the country which have the special task of watching over and furthering the interests of Russian trade and manufacture: these are the "Society for the Promotion of Russian Industry and Commerce," and the "Technical Society;" both are active bodies with a large number of members and correspondents. They are both based on principles of protection, which it is part of their duty to make known. The latter of these societies made the subject of its last congress, the means of elevating the condition and extending the resources of native ironmakers and machine builders. To this congress the members of the trades interested were invited; they were unanimous in concluding upon the desirability of raising the import duty on iron. It remains to be seen whether the Russian Government will agree with this conclusion or not; but it is not unworthy of note that the president of this society is no less a person than Prince Constantine, the Emperor's brother. His presidency is an actual, virtual one, the discussions of the society being under his chairmanship. To the joint action of the two societies is due the existence of the technical museums of St. Petersburg and Moscow, which have been abundantly supplied with carefully selected specimens of the mineralogy and metallurgy of Russia.

The collection at the Polytechnic Museum in Moscow is deserving of special mention. It shows in a very complete and striking manner the mineral capacities of the country, its geological peculiarities, and the development of its mining and metal-working industries. The models of mining tools, machinery and apparatus, and the completely classified ores, are of great interest. The contents of this museum, as a synopsis of the geological characteristics and mining capabilities of Russia, will, together with official returns, be our guide in this sketch.

The largest number of mines and furnaces are to be found in the Ural Mountains, and the whole department of the Ural. Most of these have been called into existence by the Government. Together with the Government mines are many private holdings, which pay dues to the Government. The payment of royalty dates to the times anterior to the abolition of serfdom, when mining concessions—ground and serfs together —were made against payment of a five per cent. royalty in addition to the usual ten per cent. tax on gross returns. These works now pay a fixed sum yearly, the Government having capitalised its demands. The province of Olonetz in the north, as well as Ekaterinoslav in the south, and Poland, also pay considerable sums on account of mining concessions therein. Private works on a large scale exist in Kaluga, Tula, Vladimir, Kostrama, Nijegorod, Scusa, and Orel Jonner, in Minsk, Wilna, and Mohilno, and lately a good many similar works have been opened in Finland and Poland.

On looking closely into the condition of the Russian iron manufacture we find it in a very defective condition, compared with that of Western Europe. The Government works give no financial result, in consequence of their bad administration, and private establishments appear to lack energy. In a country like Russia, rich in minerals and cheap labor, very different results ought to be shown from those actually attained.

Perhaps there is one ground of excuse which has to be admitted. Fuel is scanty: wood is dear; and the ways between the mine and the furnace are frequently defective, and always difficult. The forests of the Ural are growing thin, and the coal fields are insufficiently worked and scantily provided with communications. So long as these hindrances stand in the way, any measureable extension of the Russian iron manufacture is impossible. At the exhibitions last held in St. Petersburgh and Moscow, an endeavor was made to put Russian charcoal iron in as favorable a light as possible; since, with all due regard to quality, only the prices of the works of Olonetz, and Finland, places comparatively near the metropolis, were slightly more advantageous. The exhibition of ores from these places was very rich; fresh pits are being opened almost daily. The thirty new specimens of Finland ore show a high percentage of iron, ranging from seventy-two down to fifteen. Rachette's system of heating is adopted in Finland, and from the enterprise shown by that province, there are good hopes of its success.

The following qualities are compiled from official returns for 1874. In that year the Government works in the Ural, in Olonetz, Poland, and South Russia, produced: cast-iron 202,501 tons; wrought iron, 8,994 tons; steel, 1,151 tons; shot and shell, 8,203 tons; steel cannon, 146 tons; iron cannon, 241 tons; various other goods, 106½ tons; armor plates, 169 tons; locomotives, 177 tons; steam ships, 121 tons; swords and bayonets, 46,695; gun barrels, 5,725; percussion tubes, 577,401. Private works produced:—In the Ural: cast iron, 227,419 tons; wrought iron, 164,164 tons; steel, 1,121 tons; Central Russia: cast iron, 54,090 tons; wrought iron, 29,596 tons; Poland: cast iron, 22,155 tons; wrought iron, 13,064 tons; South Russia: cast iron, 7,062 tons; wrought iron, 7,121 tons; other parts of the empire: cast iron, 1,270 tons; wrought iron, 6,194 tons; steel, 4,193 tons. The average total production of Russia for some time past has been from 306,500 to 322,600 tons per annum. Two-thirds of this total are produced in the Ural.

Although both East and West Siberia are rich in ores, they lie fallow, and a large proportion of the make of the Ural goes to Siberia. The one and only means for raising the iron trade of the latter district is in the use of mineral fuel. In certain parts of the Ural coal is found in ample supply, and needs only energetic measures to be taken for its extraction, and a sufficient railway system to provide for its distribution. Of these facts the Government is already well aware. It should be particularly pressed upon it to pay great regard to the abundant supplies there are of magnetic ore. In this connection is to be mentioned the mineral district of Goroblagodat, on the slopes of the Ural. Goroblagodat is a rocky mass, formerly covered with forests. It is perhaps the richest mineral district in all Europe. The wealth of this district was not known until the beginning of the eighteenth century; and the first workings there were not opened until 1730, in the reign of the Empress Anna. The summit of the hill is 490 feet higher than the Kushva workings, and is a mass of porphyry syenite, upon which, on the east side, lies a deposite of magnetic ore, 280 feet thick, descending to an unexplored depth below the bed of the valley. At the foot of the hill is a stratum of syenite, stretching half way up its slope; upon this the naked ironstone is piled to the summit. As the ore lies thus exposed extraction is effected in the simplest manner, with quite primitive tools. Even in the pits which have been sunk for the purpose of getting a more compact ore there is no difficulty in extraction. The workings have so far yielded 36,000 tons of mineral a year, which are smelted in five blast-furnaces in the neighborhood. The registers of the mine were burnt in 1813, and the available data concerning this mountain of ore do not go beyond that year. Reckoning by analogy, the total output must have been 1,600,000 tons; since from 1813 to 1872 there were raised 1,290,322 tons. The store yet unexhausted is estimated at 6,400,000 tons.

The Polytechnic Museum in Moscow possesses a rich collection of ores from this district as well as from that of Tagile, and from the so-called magnetic mountains of the Southern Ural. The latter district is distinguished for its magnetic ironstone; the museum also contains brown ironstone from the district underlying Moscow to the south, and from Poland and Finland. The coal resources of Russia we may make the subject of a later communication; for the present we content ourselves with the observation that capital and enterprise have here the prospect of large earnings, which the building of railways between the coal and iron fields would help materially to increase. The only works using coal, which we have now to mention, are the Bank of works in Western Poland (making 2,260 tons of pig a year), and the Lissischauk works in South Russia, province Ekaterinoslav. The latter are Government works; they were founded, in 1866, as a model establishment to stimulate private industry, and to encourage the opening up of the Donetz coal field. Two private establishments were called into being by them —the New Russian Company, a joint-stock concern in Ekaterinoslav, and that of Pastukhof, in the government of the Don Cossacks. Local coal only is burnt in both these latter, as in the Government establishments.

Coal is used for making wrought iron only in certain works of Western Poland, in the Imperial works at Kamkofsky (Viatka), and those of Lugan, in the province of Ekaterinoslav. In rolling mills coal is employed only at the Alexandrofsky Works, owned by M. Usevolojsky, and those of M. Lazaref in the Ural. Technical methods are a little too prone to keep the *status quo ante;* modern improvements are not much regarded, if we except Siemens puddling furnaces, which are found here and there. Notwithstanding, heavy work has been done; stout boiler-plate has been made, and armor-plates, 15 inches thick, and weighing 1300 pood, have been rolled. The rail manufacture is in a low condition. This is to be regretted, as the railway wants of Russia are very large. The largest rail-making house is that of Pantiloff, at St. Petersburg. It produces an annual average of 1,000,000 pood of rails and 200,000 pood of other articles. The works occupy about 2000 men; the coal used, as well as the cast and wrought iron, are imported from England. Of the former, 20,000 tons, of the latter 11,000 are worked up annually, together with from 6000 to 8000 tons of old rails and scrap. In the government of Nijni, in the Ural, as well as in South Russia, there are a few rail mills, but they are of small importance. With the other Russian works are to be enumerated those, ten in number, belonging to the "English Vicksounsky Company;" eight of these are in the government of Nijni Novgorod and one in Tambouf. The company smelts its own ores, employing about 3000 workmen, and producing bar, sheet and wire. The largest owner of mining property in Russia is Mr. Paul Demidoff. The whole city of Nige Tagilsk, in the Ural, belongs to him; his head offices, wherein is transacted the business of thirteen mines and works, are here. His possessions extended over a million and a half acres, and consist of mines of ironstone, manganese, copper, lead, gold, platinum and diamonds. Bar iron and boiler-plates are the chief products, steel is unimportant; the total make is 21,700 tons. Steel-making is beginning to progress in Russia, especially the making of crucible steel, which is used for steel cannon; in this connection we must mention the Imperial Perne and Obukhof Works, at St. Petersburg, which are under the control of the Admiralty. The manufacture is carried out in strict accordance with the most advanced requirements of science. The Bessemer system has not yet been commonly introduced; Pantiloff was the first to adopt it in Russia, he was followed by Demidoff, Bernadacky and Obukhof. The two latter have also adopted the Siemens-Martin system.

Ninji Novgorod is the principal market for the Ural iron, so far as concerns merchant irons and iron goods; pig-iron does not pay for freight. Most of the Ural works lie within range of the network of the Volga, and are thus in tolerably easy communication with their market. The works in the departments of Vladimir and Nijgerod also bring their goods to Nijni Novgorod, the total amount brought there being estimated at 150,000 tons. Heavy goods are forwarded from the works in flat-bottomed boats, several of which are joined together and called a river caravan. They float down the tributaries of the Volga into the main stream, rarely getting into it without risk and never without trouble. The iron sold passes through two pairs of hands before it comes to the retailer, the difference between consumer and producer sometimes rising as high as 9s. per cwt. The prices of merchant iron are regulated by the weather and the results or prospects of the crops. This is accounted for by the fact that agriculture in the neighborhood of the mines is on a very small scale, and its products are inadequate to the wants of the inhabitants and the workmen, so that the larger portion of the food consumed in the Ural has to be brought, at great expense, from a distance. In the interior of Russia the patriarchal system necessary during serfdom is still retained, and owners and principals take the material necessities of their workmen into consideration. They are in the habit, accordingly, of laying in a twelvemonth's store of provisions for their employés, and retailing to them at cost price; the prices of iron and of agricultural produce are thus brought into an interdependence. The iron brought to Nijni Novgorod is carried north as far as Riga and south as far as Odessa. The south-west part of Russia takes the make of the works at Tambof, Riazan, Vladimir and Kaluga direct. The governments south of Nijni get their iron from Laishef, in Kasan, a halting-place for the Siberian caravans.

A SCHEME for a United Drainage District for Birmingham and the surrounding places has been adopted by the joint committte, subject to confirmation by the various sanitary authorities within the united district. The district proposed is to include Birmingham, Aston, Balsall-heath, Handsworth, Harborne, and Smethwick urban districts, part of West Bromwich urban district, and parts of the rural districts of West Bromwich, Solihull, King's Norton, and Aston, and such other places or districts as the Local Government Board may think fit to include.

The objects of the scheme are:

(1) The disposal of the sewage of the various towns and places within the district in such a manner as shall prevent the pollution of the river Rea, and the river Tame, and any of their tributaries.

(2) The prevention of the pollution of such rivers and tributaries from any other cause, either within the district, or previous to their entering the district.

The board is to take charge of outfall works for the whole of the district, and of such intercepting sewerage works as may be necessary to convey the sewage of each town or place from the main sewer to the boundary of the outfall works. The local draining of each town or place will not be included in the powers of the board, but the board is to define the boundary of all outfall works which may comprise tanks or works for subsidence, filtration, or other treatment for the purification of sewage, and land for the purposes of irrigation, filtration, or utilisation of sewage.

THE PROFESSION OF ENGINEERING.*

By Professor FLEEMING JENKIN.

From "Engineering."

Gentlemen, — On considering the addresses which I have had the honor to deliver in this university, I found that I had never spoken in praise of the profession which you have entered. Perhaps the omission was due to an unconscious pride grounded on the conviction that no one could doubt the value of the work done by the engineer; nevertheless, you may perhaps be glad to listen for once to the eulogy of our common occupation. Nor will my words be useless if they serve in any degree to fan the enthusiasm with which, as I hope, many of you are entering upon the business of your lives.

Let us consider why a man who needs to gain his daily bread should select one profession rather than another. Putting aside commonplace motives, such as are afforded by the existence of family connections or interest, I think a man will choose his occupation wisely if in it he seeks to find scope for the healthy activity of his best faculties, and the satisfaction due to the knowledge that his work will benefit others as well as himself. Some definition of the business of an engineer must be given before we can discuss how far our occupation fulfills the conditions now laid down, and I think that I shall hardly make that definition too broad if I claim as our special work the practical application of science to the satisfaction of man's material wants. Food, clothing, and shelter, light and heat, air to breathe, water to drink, these are the first material wants of man, and wherever science aids in their production or distribution there the engineer steps in. Exclude science and the definition fails; the husbandman sowing and reaping after the manner of his fathers, is not one of us, but already by right of science we claim his sons as our subjects; we plow, we sow, we reap, and agriculture henceforth is ours. Similarly, wherever exact knowledge replaces traditional art in the production of any fabrics or manufacture, the head and hand of the engineer apply the means. The mill then replaces the solitary worker, and it is the engineer who builds the mills, who fills the mills with his machines, who drives the mills with his engines, who carries the materials in his steamers and his railways, which again serve to distribute the produce to man. In all these cases we simply apply science, that is, exact knowledge to production or distribution. The means of attack and defence are among the material wants of man, and although we are not soldiers, yet it is we who now arm the nation. Shelter is one chief material want; it is the duty of the engineer to provide buildings so constructed as to be healthy. Drainage, warming, ventilation, all lie within our province, since all these subjects require applied science. The simple builder may repeat the traditional house, the architect may adorn where he is able, but it is the engineer who must use the discoveries of the philosophers to improve the health and increase the comfort of his fellows. We see already that the scope of the engineer is certain to be wide, and on considering what branches of science fall within his province, our conception of his field of action will be still further enlarged.

Mathematics and natural philosophy need only be named to be accepted as heading the list of our servant sciences. Chemistry finds its application in the improvement of manufactures, in mining, in sanitary engineering, and if any chemist not an engineer should claim exclusive jurisdiction over certain useful applications to the improvement of manufactures, I would first observe that in applying his ideas he requires our machines; and secondly, I would point to the progress made when a Bessemer or a Siemens is at once engineer and chemist. I claim that every exact science, by which I mean every science the results of which can be numerically expressed, requires for its application to the wants of mankind the assistance of the engineer.

* Address delivered at the Opening of the Class of Engineering in the University of Edinburgh, November 1st, 1876.

Passing to what may be termed the historical sciences. It is the engineer who *uses* geology whether in mining, in the construction of roads, or the collection of water. If I think of botany, I say that our foresters should be engineers. It is the engineer who applies the teaching of physiology to the improvement of our dwellings and to the purification of our rivers, and thus we see that if these historical sciences are less exclusively our own than those which deal with numbers, yet we may say that wherever any science whatsoever is concerned with production or distribution, the engineer cannot be repelled as an intruder.

No man who loves exact knowledge can fail to find scope for the exercise of his intellect in the practice of the engineer. This practice is, moreover, curiously suited to men of the most opposite temperament. The sedentary man can work in his study, the active man need hardly leave the field; the man who loves home life may find abundant work in quiet country towns, the adventurous man may push his fortune in distant almost in desert lands. The man of routine and method who loves to do well that which has been done before, will find himself popular, while the inventor who creates new wants and new wealth is the idol of the profession. The recluse who loves solitude may work in peace, but the born ruler of men may command peaceful armies. The cautious man will meet with praise and the bold financier may dispose of the savings of a nation. The sense of beauty is not required, but if any one of us should possess a taste, unfortunately too rare, his scope might be envied by the greatest artist. The man of high education commands resources of inestimable value, but the simple workman who can observe nicely and reason accurately may take the place of a leader. Language, letters, rhetoric have been gifts denied to many of our greatest men. Yet the linguist possesses great advantages. The man of letters is certain to find readers and the speaker to collect an audience. Many a contented engineer lives out a useful life administering a system of tradition, while his ambitious brother directs schemes which may change the face of a continent and found the prosperity of nations. Two conditions, and these only are needed, the man must love his work, and have ability to perform it.

Let us then take it to be true that the man who loves science in any of its branches and takes pleasure in its practical application may as an engineer find ample scope for the exercise of his intellect. There still remains the question: May he find in that exercise the solid pleasure of believing that he is working for the general good? To many of you the question may seem almost idle, but at some time or other to older men the question will at times occur, Why am I working? Am I not disquieting myself in vain? Money making is no great pleasure when once bread for the family has been earned ; social distinction is like the fair fruit filled with ashes. If as older men you are to work with the fire of youth, other motives are needed, and it is no idle question to ask whether in our profession these other motives will rise and lead us on. I for one do not doubt it. By our work we feed mankind, we clothe mankind, we house mankind. Through our work deserts are peopled and old countries teem with a new life. We promote wealth which in its simplest sense is but well being. Let who will look backward on a past golden age embellished by a haze permitting imagination to people its pastures with idyllic beings. We face the present with faith in a future moulded by knowledge of the truth. If the husbandman does well producing food, the engineer doubling that food does better. The charitable man gives bread but the engineer gives work whereby freemen may earn their bread. When the engineer cheapens cloth he betters the condition of man more than if he halved his cloak with a beggar. To cheapen dwellings is better than to build an almshouse. If existence be a boon, and I do not doubt it, the engineer is indeed a benefactor, his creations have called peoples into existence, he creates wealth and wealth creates men. These things I hold to be his greatest deeds. I almost reluctantly speak of the more direct benefits he confers by giving pure water, fresh air and cleanliness to the dwellers in towns. The direct action of the sanitary engineer is more visible, but is not really more beneficial than the work of all other branches of the profession. The man who by a better form of bearing diminishes friction thereby cheapens production and clothes the poor. Our business is to supply the material wants of men, and he who can do this is doing well.

Though I claim much, do not suppose that I claim supremacy for our work, or call on all to join us. We do good, and we have great scope, so much I claim fearlessly, but I neither say we do the chief good, nor that we have the widest scope. It is well to remember that man does not live by bread alone, and if the engineer can create a nation he can do but little to determine what manner of nation it shall be. This duty falls to men whom some may call prophets, some poets, some philosophers, some the divine teachers of mankind. We, the men of exact science, seeking for material good, do not belong to this band; we can only print their words, spread their doctrine, and follow their guidance. We miss, too, the direct sense of alleviated suffering which must be the physician's chief reward; but yet our steamers fetch his drugs and our mills prepare them. The arts which are concerned in the production of beauty, are all, save one, strangers to us, and even although the province of architecture is our natural heritage, we have failed to claim our right. The history of the great past is of little account to us, neither is it our task to mould or to administer the laws which regulate the relation of man to man.

Nevertheless, although these things do not lie in our province, although we may grant that higher duties may fall to other men with greater gifts, yet we may be pardoned if we remember that where there be prophets they will prophesy falsely, that the physician still walks by an uncertain light, that the lawyer may become the slave of words, and the politician may blight where he would fain bless, whereas I believe that I am making no idle boast when I claim that if we as engineers labor diligently in our vocation, whether our opportunities be great or small, we shall not labor in vain.

Hydraulic Propulsion of Tramway Cars.—About midway on a line or network of tramways, or at any other point of the same line, a motive-power engine is, according to the invention of M. L. Rousseau, C.E., of Brussels, mounted and arranged in combination with pumps and apparatus in a similar manner to those employed in ports, docks, or warehouses, where the lifting apparatus are actuated by hydraulic pressure. For this purpose a pipe or tube for conducting water under pressure is laid down along the whole of the line of tramway or its branches, and in communication with a reservoir or receiver. At suitable distances apart valves or taps are placed in the said pipe or tube in order to supply water under pressure to the carriages of the train, which are placed at certain stations in communication with the reservoir or receiver above mentioned. At these different points or stations each carriage completes or renews and stores away the necessary quantity of water under pressure which is required to enable it to act automatically in the distance comprised between two hydrants for taking in the water.

In order to maintain the water under pressure stored in each carriage, a receiver is fixed either horizontally or vertically under the floor of the carriage. This receiver is composed of one or more cylindrical metallic vessels containing compressed air at high-pressure (from 20 to 30 atmospheres), according to the power required. The compressed air contained in each receiver acts by its elasticity similar to a spring, either direct or by means of a piston, on the water supply contained also in one or more cylindrical vessels. The water under pressure in the reservoirs or receivers puts in motion the mechanism, and thereby gives rotary movement to the wheels of the carriage. In order to put the mechanism in motion, an ordinary hydraulic capstan is employed, or the well-known multiple cylinder apparatus of Brotherhood or West, or the well-known cyclo-dynamic machines of Mathon, or any other suitable mechanism, in order to obtain the same result.

Ulverston Furnaces.—One of the three furnaces built by the North Lonsdale Iron and Steel Company, at Ulverston, has been blown in, and the remainder are expected to be lighted in a short time.

TRANSMISSION OF POWER BY WIRE ROPES.*

By ALBERT W. STAHL, M. E., Cadet-Engineer, U. S. N.

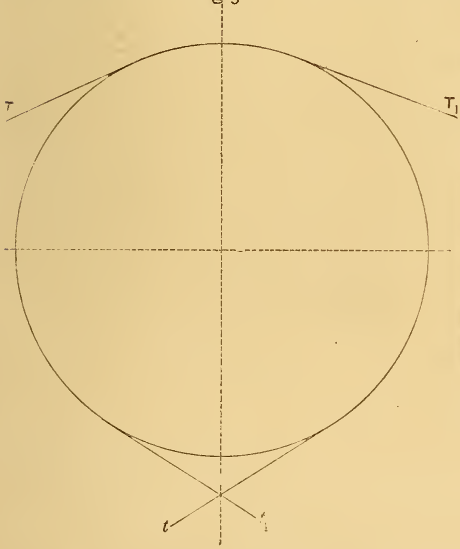
III.

Section X.

PRACTICAL DIFFICULTIES.

In the transmission of power by wire ropes, the greatest attention must be paid to keeping the ropes and the lining of the wheels in thorough repair. Even when the ropes are exceedingly taut on the wheel at first, it has been found by experience that, after a short time, the ropes stretch considerably. This causes the ropes, particularly in summer, to sag

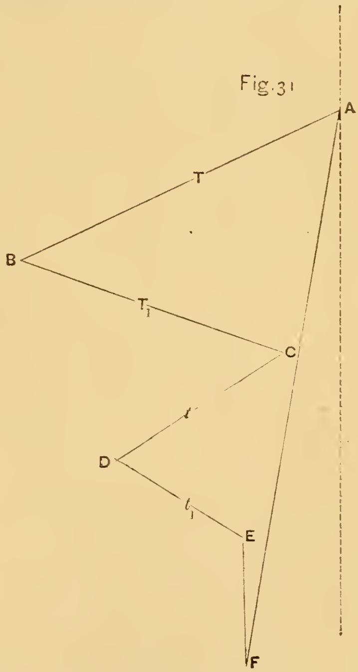
Fig. 30



so much as to incapacitate them from transmitting the whole force, causing them to slip on the wheels; or the ropes begin to drag on the ground or other obstructions. This evil may be partially remedied by shortening and again splicing the rope, which, however, should be avoided as long as possible, as the rope is ruined more rapidly by several re-splicings, than by long running under the regular working tension. I must remark that a wire rope stretches more as the wires make a greater angle with the axis of the rope; but as a rope having its wires parallel to the axis would be useless, we must strive to keep the angle at its minimum value.

Experiments made with a view to stretching the ropes before putting them into use have not been very successful. It is only lately that the problem has been partially solved by a method of compressing the ropes while subjecting them, at the same time, to a great tensional strain. Wire ropes with wire centers, as sold in the market, are stretched in this manner from .22 to 1.2 per cent.

Fig. 31



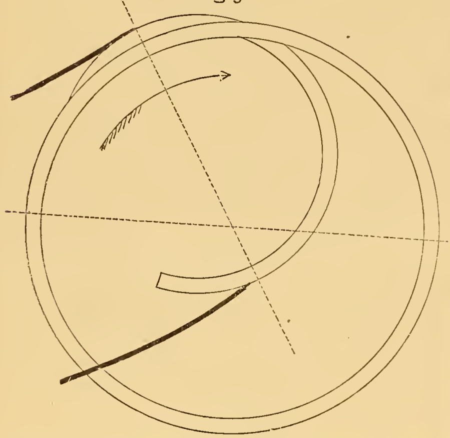
Wire ropes with hemp centers, as generally employed for the transmission of power, are stretched from .71 to 2.6 per cent. of their original length, without at all impairing their strength.

Although this is a great step in advance, reducing the stretching of the rope, with its accompanying disturbances, to a minimum, yet even this is not sufficient to maintain a constant tension and deflection in the rope, and we are often compelled to use other means to restore to the same its original tension.

* A graduating thesis at the Stevens Institute of Technology, Hoboken, N. J., June 30th, 1876.

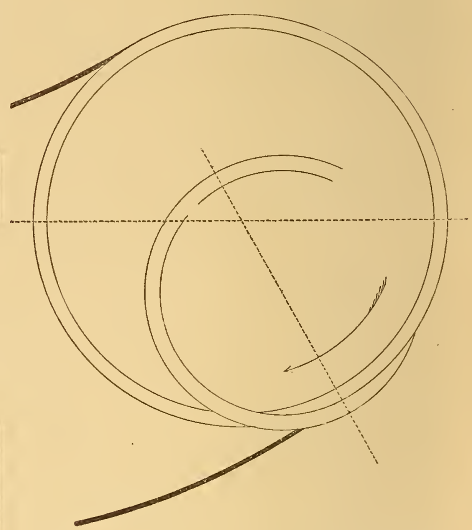
The simplest and most effective way of attaining this end is by re-filling the rims of the wheels, *i.e.*, by increasing their respective diameters to the proper amount, which is done in the following manner. (See Figs. 40–43.) Fig. 40 shows the cross section of a wheel with leather filling, and Fig. 41 the same wheel with its diameter enlarged by the superposition of the new filling, which is best made of poplar or willow-wood. It is made by taking straight pieces of about $1\frac{1}{4}$ inches in thickness, planing them into the necessary shape to fit the rim of the wheel, or merely cutting them into that shape by means of a circular saw, and providing their upper surfaces with grooves for the ropes. These pieces are made from 45–70 inches in length,

Fig. 32



and are provided on their insides with saw cuts going half-way through the wood. When we wish to put on this filling, the pieces are steeped in water for a day or two, to render them more flexible. They are then nailed to the leather filling by means of suitable wrought nails, which should be somewhat longer than the thickness of both fillings together, so that after passing through the leather they may strike the iron below and be clinched, thus affording a better hold. The nails must be driven as shown in Figs. 41 and 42, and especial care must be taken that there are no projecting ends within reach of the rope. The whole operation can easily be performed in an hour, without throwing off the rope. In case the filling of one wheel in this manner is not sufficient to accomplish the desired result, we perform the same operation on the other wheel. If this is still insufficient, the whole process is repeated with a second layer. When the rope has finally become of a constant length, which usually takes place in the course of a year, we may carefully remove all but the leather filling, and then shorten the rope to the proper length, allowing it to run on the original filling. After this treatment, there is usually no more trouble to be apprehended from this source, but there are some other difficulties which must be guarded against.

Fig. 33



When the transmission is in good running order, the ropes should run very steadily and without swaying laterally. If the latter does occur, it is due to one or more of the following causes, (leaving out of consideration the slight swaying motion produced by the wind, or by an excessive velocity);

1. When the wheels are not perfectly balanced or are not true circles.

2. When the wheels are not in the proper plane.

3. When the filling is in bad condition.

4. When the rope is too much worn.

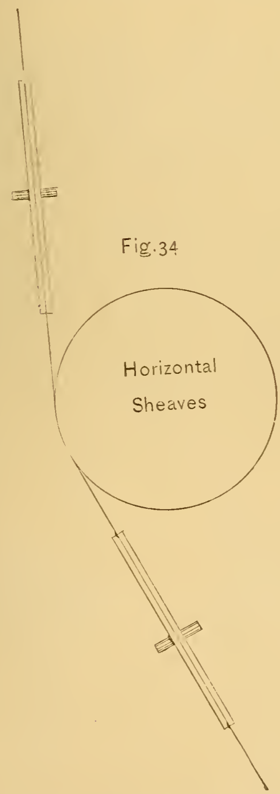
5. If the rope has been badly spliced.

6. If the rope touches the ground or other obstructions.

1/ It is absolutely necessary to balance the wheels perfectly; as, if they are not well balanced, the centrifugal force, at the velocity with which they are driven, exercises a very prejudicial effect on the bearings of the shaft, as well as on the rope. The bearings wear out faster and waste more power in useless friction, while the rope begins to swing, sometimes to such an extent as to be thrown violently against the side of the wheel groove thus wearing out very rapidly.

2/ In mounting a transmission, the greatest care should be taken to get the wheels in the same vertical plane, and the shafts perfectly horizontal, inasmuch as any deviation from this position immediately shows itself in the rope.

Fig.34



3/ In case the filling is in bad condition and worn unequally, it causes the rope to swing in a vertical plane. The remedy is to cut the filling so as to make it equally thick all around.

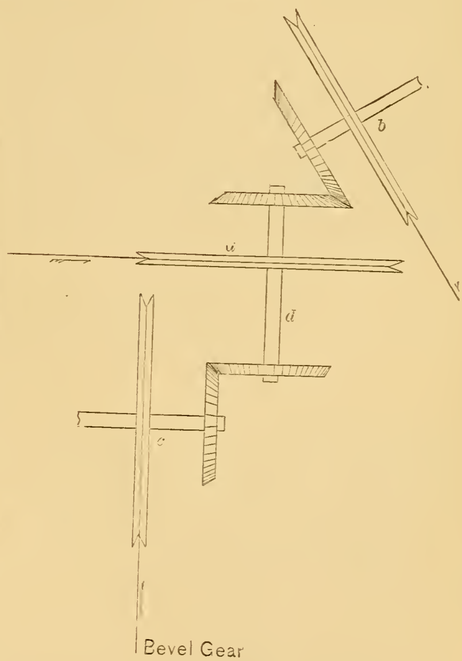
4/ If there are ends of wires projecting from the rope, then every time that one of these projections passes over the wheel, the rope receives a slight shock, causing it to swing. The same action takes place if torn or loose strands occur in the rope.

5/ If the rope has been badly spliced, or given a false turn, it will not run steadily.

6/ When the rope has stretched to such an extent as to touch the ground or other obstructions, it begins to swing violently. An attempt has sometimes been made to remedy this by putting in a little roller or guide, which, however, usually makes matters worse.

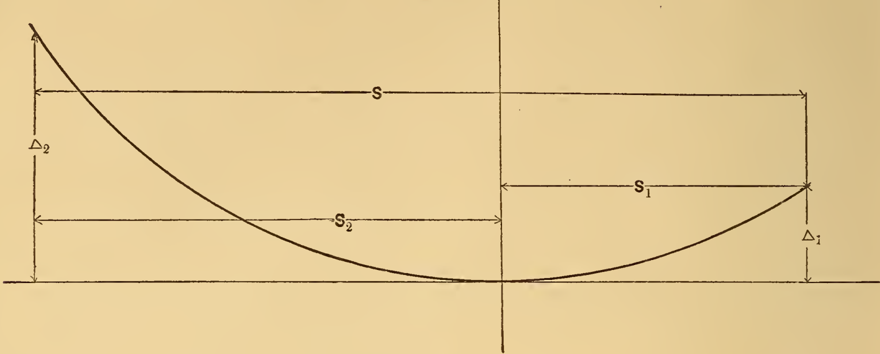
There are some other causes which induce an irregular action in the rope. For instance, if a wire rope is transmitting a constant power to a certain distance, and if the wheels, ropes, etc., are in good order, it will run steadily as long

Fig.35



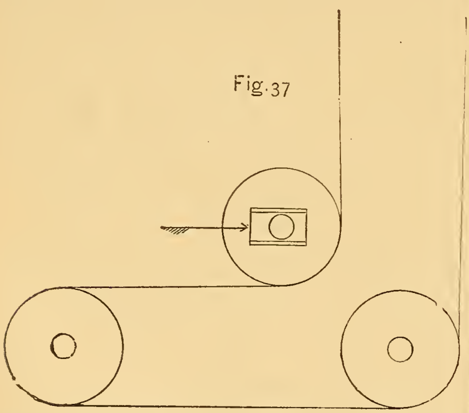
as the power transmitted corresponds to a certain tension and deflection in the rope. But now, if some of the machines are suddenly thrown in or out of gear, the tension in the rope and its corresponding deflection will be changed, thus causing the rope to sway gently in a vertical plane. The result is, of course, that the motor will change its speed to suit the new demand for power. This property is of great value, particularly in long transmissions, as it prevents sudden changes in velocity, the rope itself acting as a sort of governor.

Fig. 36



Another cause of swinging is found in very powerful transmissions, where it becomes necessary to use two ropes to transmit the power, connecting the two wheels by a differential gear. The object of this gear is to equalize the tension in the two ropes, as neither this nor the diameter of the wheel can be exactly maintained in two wheels running side by side. As the cross-head of the differential gear is firmly connected with the shaft, while the wheels with their bevel-

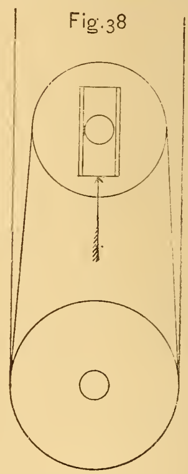
Fig. 37



gear run loose on the same, the result is that when the tensions or the effective diameters of the wheels are not the same in both, there is an additional rotation of one or the other, caused by the differential gear. This produces slight vertical oscillations, which, however, have no prejudicial influence on the working of the ropes.

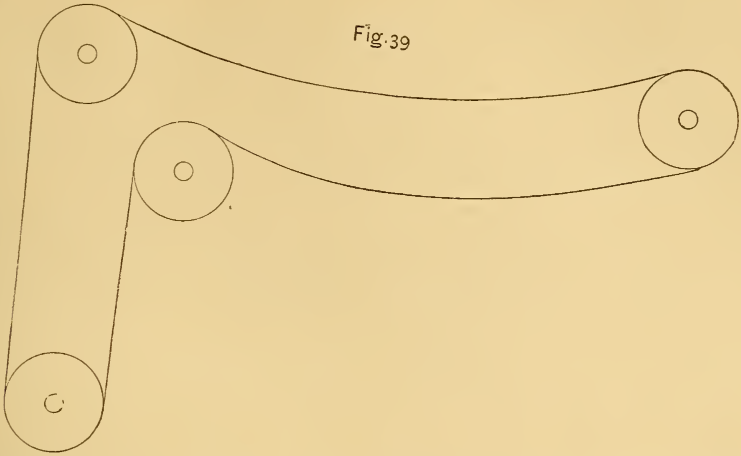
Wire ropes are sometimes used to transmit the power of a steam-engine to a distant building, or to combine its power with that of some hydraulic motor. In such cases, we must be very sure of the regular action of the steam-engine; as it often happens, particularly in the case of an expanding, single cylinder engine, with a light or badly balanced fly-wheel, that the speed during a stroke is irregular. If we attempt to transmit the power of such an engine by means of wire ropes, the result will be a series of oscillations in the latter, in synchronism with the stroke of the en-

Fig. 38



gine. When this occurs, it can only be remedied by using a heavier and better balanced fly-wheel, or by adding a second cylinder to the engine. These irregularities come under the heading (1), because the effect of a badly balanced fly-wheel, is identical with that of a badly balanced driving wheel. When a rope is used in connection with a steam engine, the latter wants a very powerful, quick-acting governor, in order to prevent the overrunning of the engine, if the rope should suddenly break. Such

Fig. 39



an accident happened a few years ago in a cotton spinning establishment in Alsace, causing the complete destruction of a large steam engine.

Section XI.

FILLING FOR THE WHEELS.

The filling first employed by Mr. A. Hirn, consisted of a strong leather belt, covering the whole rim and fastened to the same by wooden wedges. With wheels of large diameter, he was ob-

Fig. 40

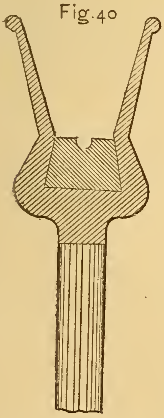
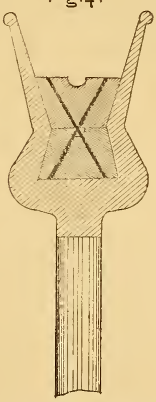
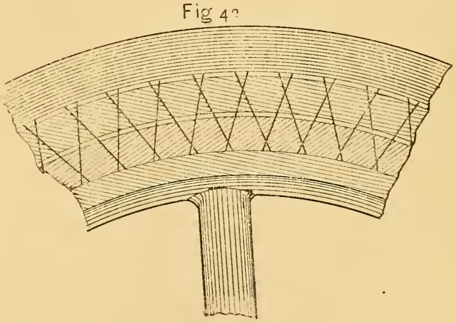


Fig. 41



liged to make this belt of several pieces, thereby weakening it considerably. This style of filling, however, rarely lasted longer than a few months. Hirn was then induced to try rubber, which has remained in considerable use up to the present day. But with very large wheels, the rubber was found to be unsuitable for the following reasons: Rubber expands greatly with heat, and when wheels filled with it are exposed to the direct and strong rays of the sun, the rubber becomes soft and is cut by the rope, or it expands over the edge of the wheel, causing the rope to be thrown off. In some cases, where the filling expanded greatly at noon, it returned to its original position during the night. On the other hand, there are cases known, when in cold nights during the stoppage of the transmission, the rope would freeze to the rubber filling. On starting in the morning, large fragments of the brittle rubber were torn out. Besides this,

Fig. 42



rubber is also slowly dissolved by the oil and grease on the rope.

After some unsuccessful attempts at filling with hippopotamus skin, willow and poplar wood were tried, giving quite passable results. Strips of poplar wood about $\frac{3}{8}$ inch thick and seven to ten feet long were planed to the proper section, softened in hot water, and then driven in without any special fastening. This process was very simple, allowing the wheels to be re-filled quickly and at

Fig. 43

slight expense. The main difficulty was that the filling sometimes became loose, owing to the drying and shrinking of the wood during the hot season. This was partly prevented by driving pieces of wire through the filling and the rim of the wheel. The wood was also softened in hot glycerine instead of hot water, thus rendering it less subject to the action of the air. In spite of these precautions, a wooden filling rarely lasted more than six or nine months, when the wood was most carefully selected; while if knots or unsound spots were present in the filling, it wore out in a still shorter period. Various other woods were then tried, but willow and poplar were found to be the most durable as well as the cheapest. As wood wears less when subjected to strain and pressure across the direction of the grain, this method was also tried, notably at the immense Schaffhausen water works. In this case, small pieces were cut, having the fibre running from side to side of the rim of the wheel. These pieces were then dried thoroughly, and frequently immersed in linseed varnish until they were completely saturated with the latter, thus becoming more durable and air-tight. Notwithstanding these precautions, some of the pieces became loose, and, although more durable than the plain wood filling previously described, they did not last longer than about one year. A further trial was made with wood filling, in which the fibres ran radially, but with no better results. But this last method has the advantage that when the rope wears a groove into the wood, the sides do not split off as easily as in the two other styles. Cork has also been tried to some extent, but it was found of little value to transmit any considerable force, as it wore out very rapidly.

Again, by wedging the groove full of tarred oakum, a cheap filling is obtained, nearly as good as leather, and not so tedious to insert.

Another plan is to revolve the wheel slowly, and let a lot of small sized ratlin or jute-yarns wind up on themselves in the groove; then secure the ends. After a day or two of running, the pressure of the rope, together with the tar, will have made the filling compact.

The first attempts with the radial leather filling were made about 1865; and it was soon found that this method of filling was so decidedly superior to all others, that it has now come into almost exclusive use. It is easily inserted by any ordinary mechanic. The separate pieces of leather are driven hard against each other in the groove of the wheel. The key or closing piece is made of india-rubber, which is first softened in hot water and then driven into its proper place. The greatest wear of the filling occurs not, as might be expected, in the driving wheels, but in the carrying sheaves of an intermediate station, and there principally in the smaller pulley. This is due partly to the great speed, and partly to the fact that the perimetral velocity of the pulley is often greater than that of the rope itself.

The life of leather filling depends on the quality of leather used, and on the radial thickness of the pieces. It is also affected by the tension, and general condition of the ropes. It may usually be estimated at about three years.

Section XII.

EFFICIENCY.

The losses in the transmission of power by wire ropes are caused by several resistances:

1. The rigidity of the wire ropes in circumflexure of the two main wheels, and through the change of angular direction at either side of the carrying sheaves.

2. Friction of shafts of the wheel.

3. Resistance of the air to the rotation of the wheels and to the passage of the rope through it.

The loss due to the rigidity of the ropes may be regarded as insensible; because when the diameters of the pulleys are sufficiently large, the wires of which the rope is made straighten themselves by their own elasticity after having been bent.

The losses due to the friction of the

shafts, and the resistance of the air, have been determined theoretically and practically. Letting, as before, t'= working tension, t_0=tension produced by bending, we have for the loss of power for the two main wheels, when

$\frac{t'}{t_0}=$	$\frac{2}{7}$	$\frac{1}{2}$	$\frac{4}{5}$	$1\frac{1}{4}$	2	$3\frac{1}{2}$
loss=	.024	.025	.024	.022	.020	.016

The greatest loss .025 takes place when $\frac{t'}{t_0}=\frac{1}{2}$, as might have been expected; for we previously found this to be the condition for obtaining the smallest wheel. But even this maximum loss is a trifle. If we consider, that with favorable conditions, we can lead a wire rope from 500–900 feet without any intermediate support, while shafting of this length would cost an immense sum, besides being exceedingly inefficient, we can well appreciate the convenience and value of this method of transmitting power.

For the carrying sheaves the loss is as follows: when

$\frac{t'}{t_0}=$	$\frac{2}{7}$	$\frac{1}{2}$	$\frac{4}{5}$	$1\frac{1}{2}$	2	$3\frac{1}{2}$
loss=	.0012	.0013	.0012	.0011	.0010	.0080

So that the efficiency in the most unfavorable circumstances, *i.e.* when $\frac{t'}{t_0}=\frac{1}{2}$, may be arrived at thus:

1. Overcoming the axle friction of the driving and following main pulleys........................ 0.250
2. Overcoming axle friction of each intermediate sheave............. .0013

Hence the efficiency is E=.975—.0013 N, where N is the number of carrying sheaves.

Section XIII.

ESTIMATES.

It is impossible to give any definite idea as to the cost of erecting and maintaining a transmission. In France, where by far the greater number of applications are made, the cost of the machinery and its erection is estimated at 5,000 francs per kilometer, exclusive of the necessary constructions at the termini, which are said to require an additional expenditure of twenty-five francs per horse power.

The average cost is about one-fifth that of belting, and about one-twenty-fifth that of shafting.

But the number of carrying sheaves, distance, height of columns, etc., vary so exceedingly, that no more than a very vague idea can be given of the cost except by making an estimate for every special case. To make this a matter of ease, I have appended a list of the current prices of several articles, the first being the price of "Wheels bored to fit shaft and lined with rubber or leather":

Diameter.		Price.
$1\frac{1}{2}$ feet		$6.00 each.
2 "		8.00 "
3 "		25.00 "
4 "		33.00 "
5 "		53.00 "
6 "		75.00 "
7 "		95.00 "
8 "		125.00 "
9 "	cast in halves	225.00 "
10 "		300.00 "
11 "		350.00 "
12 "		400.00 "

Special prices for larger wheels.

When the lining is worn out in these wheels, new filling, either of rubber or leather may be bought at 60 cents per pound.

The price of the ropes will be found in the wire-rope table previously given.

Section XIV.

HISTORICAL SKETCH.

The first transmission was put up by the brothers Hirn in 1850, at a calico weaving establishment, near Colmar. An immense mass of scattered buildings seemed to forbid the possibility of using them, and yet placing the motive-power at any one point. In this emergency, they first tried this method of force transmission, using a riveted steel ribbon to each building from the engine-house. The steel bands were about $2\frac{1}{2}$ inches wide by $\frac{1}{25}$ of an inch thick, and ran on wood-faced drums. This presented two inconveniences. In the first place, on account of its considerable surface, the band was liable to be agitated by the wind; and secondly, it soon became worn and injured at the points where it was riveted. It served, however, very well for eighteen months to transmit twelve horse-power to a distance of eighty meters.—The success of the principle was complete, but much remained to be done before the wire rope and the rubber or leather-lined driving wheel solved all difficulty, and brought the principle to be a practical reality.

The number of applications of this method of transmitting power has increased very rapidly. At the end of 1859, there were but few applications in use. In 1862, there are known to have been about 400, and in 1867 about 800. At the present time there are several thousand in successful operation. In 1864, a terrible explosion destroyed almost all of the great powder mill at Ockhta, situated about six miles from St. Petersburg. The whole establishment was rebuilt. After studying many combinations, an artillery officer proposed to profit by the resources which the telodynamic cables offered to engineers, and thus to realize the only combination which could prove successful in a powder-mill; namely, a great distance between the buildings, so that the explosion of one should not entail the ruin of the rest. The new establishment, which went into operation in 1867, is composed of thirty-four different workshops or laboratories, to which motive power is transmitted by means of wire ropes driven by three turbines, thus distributing a total of 274 horse-power along a line nearly a mile in length.

The largest transmission is that employed to utilize the falls of the Rhine, near Schaffhausen, in Switzerland. Advantage was taken of the rapids at one side, to put in a number of turbines, aggregating in all 600 horse-power. Since the steep rocky banks forbade the erection of any factories in the immediate vicinity, the entire power was transferred diagonally across the stream to the town, about a mile further down, and there distributed, certain rocks in the water being made use of to set up the required intermediate stations. In the industries we frequently meet with a similar case. Many valuable sites for water-power are lying idle in this country, for want of building room in their immediate vicinity. New England especially abounds with them. Coal being so dear there, their value is all the greater. Since the water can only be led down hill in certain directions, the cost of a canal or flume would in most cases come too high, and so the power remains unimproved. By ropes, however, we can convey the power of a turbine or water-wheel in any direction, both up stream and down stream; up an ascent of 1 in 8 or 10, or down a moderate slope as well. The power need not be confined to one factory, but may be distributed among a dozen, if necessary, located so as to suit their particular business, and not to suit the oftentimes inconvenient location of a canal.

Thus, by means of the transmission of power by wire ropes, we may utilize all this power that is now being wasted, and devote it to a useful purpose.

HOW TO DRAIN A HOUSE.*

By T. MELLARD READE, C. E.

From "The Builder."

The subject of my paper is not one to excite the imagination, to give scope to lofty ideas, or to raise emotions of the sublime and beautiful. It is essentially of the earth, earthy. To what extent the great masters of our art had to condescend to consider so humble a subject as house drainage, I have not seen recorded in our text-books. Whether this has had anything to do with the grudging attention usually paid to house drainage by the profession I am not aware. Admittedly it is an unentertaining subject and not one calculated to excite the interest of the artistic mind, fed on the exciting but not very nourishing food of the competition perspective.

The architect, as a rule, not taking any special interest in this class of work, usually, as regards the carrying out of his plans, relegates it largely to the clerk of works, or, if there be none, leaves it in the hands of the bricklayer, who hands it over to a laborer, and as clerks

* Read before the Liverpool Architectural Society, November 29th, 1876.

of works are not always paragons of knowledge and accuracy, and bricklayers are not the most scientific of men,—even though as honest as the one to whom Professor Huxley would entrust the planning of a college in preference to engaging the services of an "eminent architect,"—the drainage works are, to speak in the mildest terms, frequently unsatisfactory.

But, as is often the case, that which at first repels us becomes interesting on closer study, and with the view of promoting a more exact and scientific way of carrying out the drainage of a house, I have ventured to submit to your consideration the following practical observations on "How to Drain a House."

With the introduction of the complex arrangements of the modern house,—complex, at all events, as compared with that which satisfied our forefathers,—but more especially as the natural complement of an abundant water supply delivered to each individual house, the modern system of sewerage became a necessity. It is not my present purpose to deal with the "sewer,"—that is, the duct in the street provided by the sanitary authority which usually, and especially in towns, performs the separate functions of a drain for surface-water and a duct for "sewage." For my present purpose I assume, in my first example, that it exists, and, in my second example, that our supposed building is away from the modern luxury of a sewerage system, in which the disposal of the sewage itself becomes one of the main considerations, and is of primary importance.

Before treating of the general principles to be followed in house-drainage, I may remark that in the selection of the materials of our drains there is not now much choice. The use of glazed fire-clay or earthenware pipes is almost universal. Cement pipes have been recommended by an eminent authority, but as I have had no experience of them it is not necessary for me to do more than mention them. No one would now propose to use brick or stone culverts, or drains square in section, with sides of brick, and bottom of slate, as were formerly in vogue. Practically, then, our choice of materials is limited, but as usual there are great variations in the quality of the article supplied, not only by different, but by the same manufacturers. What the architect should insist upon is a strong, well-burned, material, accuracy in form, both sectionally and longitudinally, true sockets, and a good smooth glaze. The smaller pipes are especially liable to be twisted longitudinally, and such should be at once rejected. Pipes having a rough interior should not be used, as lumps and blisters in the glaze accumulate material round them and injure the efficiency of the drain.

At the risk of being accused of putting the cart before the horse, I will also explain the practical art of laying drain-pipes and the fall it is necessary to give them before touching upon the general question of how to design house-drainage. I do this because I consider the proper laying of the pipes one of the most important parts of drainage, and the one in which failures most often occur, and without which any system of house-drainage will not perform its functions satisfactorily. The true laying of a pipe is of more importance than its quality. An inferior, rough and crooked pipe may if laid properly under ordinary circumstances be made to perform its work satisfactorily, whereas the best made pipe in the world will only act for a time, and then inefficiently, if laid in those beautiful vertical and horizontal sweeps known as Hogarth's line of beauty, so frequently seen only in their full perfection when a drain is taken up.

The righteous indignation of the bricklayer and his laborers employed in taking it up, against the tradesman who laid it down, is only fully appreciated when, on having to take the drain up a second time, we find these honest men have put in a pipe without a socket, or a square junction, or a junction turned the wrong way, or accidentally omitted to make a joint good, or done or left undone some one of those multitudinous things essential to good workmanship. Truly the architect's bed is one more of thorns than roses.

The next thing to be determined upon is the fall, and I cannot too strongly insist upon the necessity, in all cases, of having the levels first accurately taken and a section made before the drains are put in. This is an additional trouble, no doubt, but will be amply repaid in the quality of the work. Of course, when the whole of the trenches can be opened at once, this is not always necessary; but it more often happens that the trench has to be filled up as the work proceeds, either from the nature of the ground or the exigencies of the site. The architect should, of course, aim at getting the greatest amount of fall from the sewer to the junction with the branch drains of the house, keeping in view that these should themselves have quicker gradients than the main drain. Without a section it is generally difficult to do this. A fall of 1 in 48, or half an inch to a pipe, is a good one for a main drain; but it sometimes happens that this cannot be obtained. Nay, I have myself had to lay them nearly level; but in such cases special flushing arrangements are absolutely necessary. The usual system pursued by the "honest bricklayer" is to start from the main sewer and lay each pipe to a fall by a straight-edge with a piece of wood planted on one end. The size of this piece is determined by some rule no doubt,--probably the rule of thumb; a rule, I need scarcely say, of very wide and universal application. By means of these implements the drain gradually rises towards the house; but whether it hits the exact level or falls below it, or is a foot or two higher, Providence alone can determine; at all events, I may say it is not so certain to work out right as were the two driftways through Mount Cenis. It not seldom happens that if the workman finds he has made a bungle and got too high, he either carries his drain on a level, or actually dips it the wrong way. And what does the architect do? He sees the end of the pipe at the proper level, and all the rest carefully covered up, and probably assumes that all is right.

There is another internal defect arising from this way of laying pipes; they are laid by the flanges, and the inverts, which are of primary importance, are left to take care of themselves. I have never seen outside of my own practice house-drains laid by their inverts; but I consider this should, where the fall is limited, always be done. It is readily done, but the drain-layer has to be taught, and it is a good deal of trouble to teach him, but not more than, I hope, any architect interested in the perfection of his work would undertake. The method of proceeding is by fixing sight-rails at the two ends of the drain, and sighting a boning-rod with a T-piece at the top, and a bent piece of iron or shoe to fit on to the invert at the bottom. This, of course, usually involves a correct system of levels and bench-marks, with the depths figured on the drawing. The joints should in all cases be made in cement; half Portland cement and half sand is a good proportion; and special care should be taken to scrape out the cement on the inside of the joint, so as to leave as perfect a tube as possible, free from lumps and obstructions. I need scarcely say half-bricks should not be left in the pipes, but I have not unfrequently found them there.

Having now described some of the more important structural details necessary to the efficient action of any system of drainage, I shall next discuss the best system to be adopted.

It is pretty generally admitted that all drains should be on the outside of a house, and in no cases, except through unavoidable necessity, should they be carried through it.

The soil and waste-pipes from water-closets, baths, and lavatories, should also be taken as far as possible outside. I assume, in the first place, that every sink, basin, and bath is trapped inside the house with an S trap, constructed so as to be readily cleaned. If this is not done, draughts of air will come up them into the room, conveying the stench from the organic matters coating the interior surface of the pipe, even though the sewer gases should be carefully excluded by external arrangements such as I shall presently describe. The water-closet is always fitted with an S trap, which should not exceed four inches diameter, though the soil-pipe into which it empties is better larger, and I frequently specify it five inches. I consider the pan-closet objectionable, especially since the compulsory introduction of the two-gallon regulating cistern has increased the difficulty of getting the after-flush to fill the pan. The container is a reservoir coated with filth, hidden by the pan holding the water in the basin. A basin with a trap at the side or back, called a wash-out basin, is a far better apparatus. If a pan-closet is used, it should always have the container ventilated. Baths and lavatory basins should never have their outlets into the soil-pipe of the closet: this is often done to save expense, and even the trap of the closet is used to trap the waste-pipe from basins and baths; but this is still more objectionable. The soil-pipe of a closet should in all cases be an independent pipe, into which nothing but the soil enters, and it should be carried up above the eaves of the house, full bore; if to the top of a chimney-stack all the better, and it should be, except in those cases where it acts also to take the gutter-water from the roof, fitted with a wind-guard or revolving cowl to prevent down-draughts.

We now come to the drainage proper by which all the separate outflows of waste organic matter are to be carried off and into the main sewer.

In designing a system of house-drainage we must decide, in the first place, whether we keep our rainwater separate. In the case of a house supplied with hard water it is advisable to store the rain-water, and this is best done, as is usual, in an underground brick tank cemented inside, called a terras cistern. It will nearly always be found that there are some down-spouts that, through the levels, cannot be readily connected with this cistern. These should be turned into the drain, which they will help to flush and keep clean. In cases, however, where the sewage has to be disposed of independently of a main sewer, the rain-water is rather a trouble than otherwise, and those pipes unconnected with the rainwater cistern should be turned on to the surface channels or made to flow over a grass plot. The overflow of the terras cisterns should in no case, where it is possible to avoid it, be in any way connected with the drain; if it is we can never be sure of the purity of the water, and I have known instances where the whole of the house has been connected with the sewer through the rainwater cistern; the air-space above the cistern being connected with the space under the floor of the house, the overflow being taken into the sewer and untrapped. Even if trapped we have no security, as the water in the trap dries up before the cistern overflows again. On the other hand, if the overflow be taken into an air-chambered trap supplied with water from another source, there is always the possibility of the trap choking through inattention and the sewage water backing into the tank. The overflow should be taken into an absorbent well, or discharged on the surface of the ground, which, if the levels allow it, is still better.

In some cases the sewage from the baths, basins, and sinks is carried independently into a tank from which it is pumped to be used for garden purposes. The soil alone of the water-closets is taken into the main-sewer. This is an arrangement also suitable for a house supplied with earth-closets, and one I am adopting at the New Truant Schools at Hightown. Where there is a man employed constantly who can look after the tank, and keep it empty, or plenty of labor in the shape of boys to pump it dry every day, the arrangement is a good one, and combined with the earth-closet in such cases, with land on which to use it, the main-sewer can be dispensed with altogether. In all cases where it is possible the sewage should be used before decomposition sets in. In those special instances, and these constitute a large class of cases, where there is no main sewerage, and there is not labor to keep the tank pumped frequently, other methods must be adopted. The ordinary cesspool is an abomination, containing as it does a festering and decomposing mass of filthy matter which is not removed until it attains the consistency of a solid pulp. This is the absorbent well. If such a thing has to be adopted, it should be well ventilated, and the connection of the house-drains with it effectually cut off. I am, however, trying another system, which, if it succeeds, I shall be happy to explain at a future time.

Let me describe the drainage of a large villa as recently carried out by me. The sewage or slop-tank is placed in a convenient position in the kitchen garden, and the levels so arranged that the inlet drain discharges into it above the level of the garden surface. I consider this a matter of great importance, for by doing so I get an overflow on to the surface, and it is impossible for the sewage to back up the pipe and seal the end of it to the atmosphere. I have known this purposely done, and indeed have in former times dipped the end of the pipe below the surface of the water with the mistaken view of "trapping it," but find by experience it is an entire mistake, as the first thing to be considered after providing for the flow of the water is to arrange for the circulation of the air. By no other means can we ensure the drains being kept sweet. The tank is constructed of brick in cement, vaulted over with an arch in which is an iron manhole cover; it is in no way an absorbent well, and the whole of the sewage must consequently be pumped out and disposed of on the surface or by the overflow. By such means the organic matters get oxydised in percolating through the pores of the earth, whereas in the case of an absorbent well such oxydization does not take place, but all the surrounding subsoil becomes sewage sodden as the atmosphere is permanently excluded. From the tank a drain is laid on a bank at an inclination of 1 in 80 and 1 in 16, gradually increasing as it approaches the house. This a drain should always do. There is a manhole containing at the bottom one of Pott's air-chambered traps which I will presently describe. This effectually severs the connection between the tank and the house, as all the slop-drains converge at this point. From the tank side of the S trap is carried a four inch ventilating pipe to the upright ventilator, which consists of a five inch cast-iron pipe terminating on a chimney-stack, with a cowl carried up above the chimney-pots. This also acts as a ventilator for the soil drains, as I will presently show. The slops are drawn from three situations, terminating in two cases in Pott's traps, which sever the connection between the house and the drains between it and the manhole. This completes the slop drainage.

The soil-drain commences at the main sewer in the road with a nine inch pipe, at an inclination of 1 in 10, 1 in 53, and 1 in 12. At the point where the branch drains converge is a manhole, and at the bottom is a six inch S trap built up solid in the brickwork. This trap occupies half of the manhole, the other half is an open duct, and as the drain is nine inches on the other side this open duct converges. The bottom of the duct is of glazed brick, and is laid at a greater inclination than the sewer. The manhole is contracted towards the surface, and fitted with a cast-iron manhole cover and a side ventilator. It will thus be seen that all communication between the main sewer and the house is effectually prevented. Further on the drain diminishes to six inches, and is connected with the vertical ventilating pipe by a four inch branch; it is then carried on to the water closets, as shown. The soil-pipe is carried up as a ventilator, and terminated with a cowl. Along the course of the drain are apertures for putting the garden-hose in for flushing it above the flushing-tank. There is a flushing-tank supplied with water from the main. It is of brick in cement, and is fitted with one of Doulton's valves. Occasionally the tank is filled with water by a tap from the main, the valve drawn up, and the hydraulic force developed is sufficient to clean out the drain. Had there been a convenient spot for it I should have placed the flushing-tank at the head of the drain. I have used these tanks for a good many years, and with most beneficial effect. As a rule, the amount of water running down a house-drain is insufficient to keep it clean, and frequently have I had to take up drains filled up solid with deposit, which, if they had been capable of being flushed out in the way named, might have been kept perfectly clear. By the combination of manholes and traps in every case I get a through current of air in the main drains.

The inlet is open, and the outlet is in one of the two ventilating shafts. This keeps the drain perfectly sweet. The house is entirely isolated from external influence, and the drains instead of being filled with fœcal matters are kept clean and free. The division of the slops and soil where there is main sewerage, is, of course, not by any means absolutely necessary, but is a refinement I should only recommend in a large house, where the slops are valuable in the garden, and where there is labor to dispose of them. The slops might be taken into the main sewer, the house being isolated therefrom just the same.

The manhole, with its contained trap,

is a novel feature of great utility; by it, the drain can be inspected, and if the trap should get accidentally choked, such a calamity is found out and obviated at once; whereas, otherwise, the first notice of it in many cases may be the backing up of the sewage into the foundations. It is an inspection place, which no system of drainage should be without, as, otherwise, it is impossible to say whether the drains are working properly or not.

Formerly, trapping a drain meant bottling up the gases in it, now it is recognized that no system of trapping is perfect without ventilation combined with it. There are many patterns of traps for effecting this, besides those I have used here, but I have not space to describe them.

To conclude, there is no part of the house which more wants supervision than the drainage, and no part that is more difficult to supervise. Speaking to architects, I may say that five per cent. commission will not pay for the necessary labor. I never expect it to do so; but, as it is part of the whole, I think, it being so necessary to health, that attention should be paid to it all the same. I picture to myself the happy time when $7\frac{1}{2}$ per cent. commission will enable an architect, without robbing himself, to do full justice to his client; but, I fear, at present, it is only a pleasing fiction of the imagination not soon to be realized. Admittedly the system of contract competition now in vogue, and its consequent demands on one's time, through having to specify every nail and screw, to foresee everything, and to provide for everything, is a great and increasing tax upon the mental resources of architects. Perhaps my little contribution may assist some in this difficult profession; at all events, practical description is of the utmost value to those who desire to learn, and I trust my remarks may be useful to them, if not to those who have grown gray in the service.

FIRE-PROOF CONCRETE.

From "The Architect."

Concrete as a building material may no doubt be said to be in its infancy, whether it is ever to attain to a much more mature condition or not. At all events, it appears that the action of Parliament is now being brought to the aid of an investigation of its properties ; and a certain document has been placed in the hands of the members of the Institute of Architects whereby it seems to be expected there will be some sort of information obtained from the architectural profession upon which Parliament may proceed. Lord Elcho, we are thus told, has suggested to the Institute the appointment of a Committee "with the view of reporting on the subject of 'Concrete as a Fire-resisting Material' to a Select Committee of the House of Commons." The Council has therefore nominated the desired Committee (although no intimation is given as to who are the members appointed) ; and the document we have alluded to as being in the hands of the members at large, consists of a series of questions, in answer to which those who have anything to say upon the subject may say it. The questions turn upon the mode of composition followed, the proved strength of the material so made, and the effect of fire upon it; there being a supplementary inquiry at the end which refers to one's experience of concrete otherwise than as merely resisting fire. Whatever may be the purpose of Lord Elcho, it is manifest enough that all this opens up to such architects, and no doubt other persons, as may take an interest in the subject, a wide field of practical building science.

There are two points upon which at the outset some little embarrassment may be felt. What is precisely meant by concrete ? And what is precisely meant by fire ? We may probably take it that the form of the material intended to be referred to in the questions is the more or less common-place building concrete at present in use, and that the degree of combustion to be taken into consideration is the supreme force of a great warehouse fire; and, so far as these limits go, we see a probability of the Institute Committee being able to effect something which shall be satisfactory in the way of accomplishing at least a clearer understanding than at present exists of the capabilities of the material; but still it must not be forgotten that there are now a good many diverse kinds and qualities of this concrete; and that their respective values against fire range from very high pretensions down to nothing at all; and when we also take into account that the material and its professed attributes are at the present moment the subject of rival advertisements and repeated patents which cannot possibly be reconciled to each other, we must at least be not surprised if the Committee should find itself not a little embarrassed in the end with the wealth of information, more specious than ingenuous, which will be poured in upon it. We had been inclined for a moment to ask why the names of the gentlemen who form this Committee of the Institute have not been announced; but we cannot help reflecting that, unless those members are willing to be personally assailed with circulars and calls from pushing tradesmen to a degree which may be more than inconvenient, perhaps their names are best kept in the dark.

It is a remarkable fact that the first prize-medal ever bestowed by the Royal Institute of British Architects was given for an essay on the subject of concrete. This was in 1835; and Mr. George Godwin was the winner of the honor. How far the subject has progressed since then, both in scientific intricacy and in public importance, some may find it hard to understand; whilst others may only wonder how it happens that, after forty years, we should still have settled so little about it.

At the base of the general question of the use of concrete as a "fire-resisting material" (this, by the way, is a new phrase, and a very good one, which was brought forward by the officials of the Metropolitan Board in their last—unsuccessful—Building-Act Bill) there may be said to lie the striking but quite intelligible proposition of Captain Shaw, that common plastering is one of the very best preservatives of what it may cover from the effect of the heat of a fire. Iron, whether cast or malleable, wherever it is exposed, is virtually helpless. Stone cracks to pieces. Timber of course is fuel. Brick, or in fact any other material that has passed through intense heat in its manufacture, is necessarily fire-proof to the last, except when its comparative thickness is unequal to the mechanical shocks produced by the conflagration. If, therefore, we can find a material which shall be of the nature of plastering superficially, which shall enable us to dispense with exposed iron, which shall be a substitute for stone, which shall do away with timber, and which (although it has not passed through the process of burning in manufacture) shall be substantially as good as brick-work, and as effectually fire-proof if only thick enough, it is very natural that we should look with hope to this material, as one which seems obviously to be capable of being brought to bear upon the task of fire-resistance to any degree and in any form that the conditions of building construction may incidentally require.

There are two typical and principal classes of serious fires in London and other similarly built large towns throughout the country; first, the burning of a small dwelling-house, and secondly, that of a large warehouse. The first involves, so to speak, more danger to life than to property; the house becomes suddenly filled in the dead of night with thick smoke and flame from burning timber-work and furniture, and, unless the fire-escape comes speedily to the rescue, some of the sleepers are suffocated. In the other instance, the circumstances and consequences are altogether different. Some vast depository of inflammable mercantile goods is found to have taken fire; the conflagration spreads rapidly and cannot be subdued because of its mere bulk; and it rages perhaps for days, in spite of all endeavors, until everything within the walls that is capable of being consumed is so destroyed. In the former case, when the timber roof has fallen in, and the floors, likewise of timber, have been broken and burnt through, the thin brick walls are left standing entire, and generally not much the worse. In the other case, a mass of combustible stores fall to the lowest level of the interior, where it continues to burn until exhausted; and the brick walls, even if more substantial than usual, are frequently twisted from their perpendicular and overthrown, while the iron construction is completely disorganized, the cast iron being broken in pieces and the malleable iron curled about like ribbons.

The use of concrete in both of these cases, looked at in the character of a fire-resisting material, seems to involve very much the same considerations. In the common dwelling-house, if the incombustibility of the interior is aimed at, the only difficulty is how to construct floors and roof, partitions and staircase, without sacrificing this incombustibility. In the great warehouse the problem is the same, and, in its degree, the same difficulty has to be dealt with and no other.

Whether the substitution of concrete for brickwork in the mere walling is to be included at all in the inquiry may be doubted. Again, there are considerations of economy that enter into the question, as regards ordinary houses, which in fact are of so much importance in practice that it becomes impossible to hope that anything approximating to incombustibility can ever be introduced into the common run of our dwellings. It is the interior of warehouses, therefore, to which we may virtually confine our attention.

Turning, then, to this subject, we may in the first place remember the following propositions:

It is said at present that nothing can be really relied upon as fire-proof construction except brick walls, brick piers, and brick vaulting; all of which must be, moreover, of such a substance as to correspond with the area of the building. In a depository of this kind, goods, of whatever nature, may, in a certain sense, be stored without fear. The interior is of course subdivided into limited sections which do not intercommunicate, and all that has to be considered, therefore, is what will happen to any one of these sections in the event of fire breaking out within it amongst goods of a given nature. The answer then becomes obviously matter of detail, and it is quite easy to understand that the combustion of oil itself, and indeed explosive oil, may be made to confine and harmlessly expend itself strictly within the limits of its own section, and that even the flame bursting from the windows shall find no admission to other portions of the building. As for the interior of the burning section, the whole would be brick; and, so long as it is built substantial enough, it would be perfectly fire-proof as an oven. As for doors, the primary idea is that iron is sufficient, provided the doors be double, one on each face of the wall. The question of staircases presents little if any difficulty.

Now if concrete is to be applied to this case, the conclusions to be suggested seem to be the following: So far as the brick walls go, it is not easy to see how they can be improved upon. Partitions also may continue to be of brick. In respect of stairs it is very likely that terra cotta may be considered preferable to everything else. Internal doors, however, seem already to be found to be better of concrete than of iron; although it is certainly difficult to get over the fact that they cannot after all be made without iron framework. But the floors and the roof still constitute the great difficulty; and this is simply because they must necessarily be supported at short intervals. Iron pillars and iron girders are not to be thought of; even if cased in armor of concrete or whatever else, it would be impossible at present to believe in them. Brick piers probably furnish the most truly scientific way of meeting their part of the case; and in a warehouse, where mere lightness of appearance would be but an affectation, it is doubtful whether they can ever be improved upon, especially if Staffordshire brick, for instance, be used, purpose-made. For the floors supported by such pillars, probably concrete, if made of the best materials, might be enough without any aid from iron; but, if iron cannot possibly be dispensed with, let it take the form of a diffused reticulation, and certainly not that of a series of joists, and so it may, by the exercise of ingenuity, be made capable of protection. Roofs, again, if regarded as floors, would be only a repetition of the same construction; and an external covering from the weather, composed of even timber-work and slating, need scarcely be objected to. We have said enough, however, for our present purpose, which is to show that the task undertaken by the Council of the Institute is not to be disposed of easily; and we will only add the hope that the profession, in answering the appeal, as we may call it, of Parliament, will endeavour to do credit to its scientific character.

ON THE MANUFACTURE AND DURABILITY OF THE STEEL-HEADED RAILS ADOPTED ON THE BAVARIAN STATE RAILWAYS.

By ADOLF GRAU.

From "Organ für die Fortschritte des Eisenbahnwesens."

The suitability of Bessemer steel for the manufacture of rails was investigated at the Conference of German Railway Engineers, held at Düsseldorf, in September 1874, the conclusion being that, although in most respects admirably adapted for the purpose, no method had yet been devised for counteracting the tendency of these rails to occasional sudden rupture.

After referring to a treatise by Herr Windscheid, describing the results obtained with the steel rails laid on the Coln-Minden railway in 1867, which were generally satisfactory, and also to an article by A. Petzholdt and H. von Waldegg on the subject of steel-headed rails, as manufactured at the Queen Mary Works, Zwickau, since the year 1867, and laid on the Saxon State railways, the Author proceeds to describe his own experience of steel-headed or compound rails manufactured under his superintendence since the autumn of 1868, at the then newly-erected Maximilian Works at Haidhof, the first of which were laid on the Munchen, Augsburg and Bamberg railway in 1869.

During the year 1874, blast furnaces, erected at Kamsdorf, Thuringia, in connection with the Maximilian works, were blown in, and from thence the supply of crude iron for Bessemer steel is obtained; before that time the iron used for the purpose was either of best English hæmatite pig, or that of the Osnabrück, Niederschelden, and Styrian districts, the process of conversion being partially regulated by the spectroscope.

The rail-pile, after heating, is hammered, reheated, rolled into the finished rail, and sawn to the desired length. From twelve to twenty of the rail-ends, thus cut off, are each day tested by doubling under the steam hammer (seldom effected without signs of fracture); others, again, are subjected to the test of a weight of 11 cwt. (10 centners), falling freely through a distance of 9.84 feet, the points of support of the rail under trial being 3.28 feet apart, the limit of depression for that distance being fixed at 5.9 inches; and in all cases this has been satisfactorily borne.

Bars were placed on each side of the steel head-plate with the design of preventing the burning of the former; but this arrangement was, in 1871, discontinued, it being found that, in the process of rolling, these protection plates generally were extended too far up the sides of the rail-head, and when subjected to traffic separated from and were stripped off the steel portion, although no accident occurred through this.

The rails, which were rolled from this form of pile in the years 1869-70, failed to the extent of from 1 to 2 per cent. of the total production. In 1871, however, there were only a few instances, and since then the rails have been totally exempt. Where it occurred the separation of the steel from the iron proceeded so gradually as to render the withdrawal of the rails unnecessary until six months after the first signs of weakness had appeared. The rails manufactured in 1871 were, however, subject to another form of failure, which first presented itself in the shape of dark-colored streaks, extending from the rail-end along the head, developing into cracks of from 3 to 6.5

feet in length, followed by partial breaking up of the surface. This was attributed to the unsuitable quality of the steel, and might probably have been avoided by a more careful conduct of the conversion process and testing of the surplus rail-ends.

The absolute ruptures were few. The Author is aware of only nine instances; in each case they took place at the fish-bolt holes, which are of rather large dimensions, viz., 1.46 inch by 0.98 inch, the outer hole being 1.12 inch from the rail-end.

In 1871 the form of the steel head-plate was modified, it being rolled with a projection on the under surface, to insure better combination with the iron portion of the rail, and this form has been adhered to up to the present time.

During the last two years rolls have been erected for the special purpose of separating the steel and iron in surplus rail-ends, the steel being returned to the crucible, whilst the web is cut from the foot, and both are utilized in making up the new piles.

As regards resistance to wear, the head of the compound differs slightly from that of the steel rail, in that the former must be composed of metal of a softer and more weldable character (to insure combination with iron) than is necessary for rails made entirely of steel.

The following table shows the amount of wear of the compound rails, measured at their mid-length:

Year of Manufacture.	Amount of wear. Inch		Millimeter.
1869	0.039	or	1.0
1870	0.047	or	1.2
1871	0.019	or	0.5
1872	0.019	or	0.5

The experimental steel rails laid on the Cöln-Minden railway, after being subjected to ten years' traffic, show an amount of wear of from 0.08 inch to 0.12 inch.

The quantity of steel-headed rails originally delivered to, and the proportion of the same requiring renewal on the Bavarian State railways, including all the cases of failure already described, is shown in the following table:

(*See Table on next column.*)

If the first delivery of rails in 1869 be

	Original delivery. Tons.	Renewals. Tons.	Percentage.
1869	1,393	124	9.00
1870	1,797	61	3.40
1871	2,807	141	5.00
1872	4,802	1	0.03
1873	3,917	..	..
Total	14.716	327	2.23

omitted from consideration in the above table, there will remain 13,324 tons delivered as against 203 tons, or only 1.5 per cent, of renewals.

Similar steel-headed rails were also laid on the East Bavarian railway, in the year 1869, at places where the gradients are 1 in 100, and the curves of 14½ to 26 chains radius, the percentage of renewals up to the end of the year 1873 being as follows:

1869	0.60	per cent.
1870	0.00	"
1871	2.65	"
1872	0.00	"

It should be remarked that the rails for the East Bavarian railway were not made until after those of the same period, 1869, had been completed for the State railway, the experience gained in the meantime accounting for the great difference in the percentage of renewals, viz., 0.6 as against 9.0 per cent.; and amongst the causes of failure there were only three cases of rupture, viz., two through the fish-bolt holes, and one at a distance of three feet from the rail-end, the remaining defects comprising longitudinal splitting, &c.

If the above results are considered unfavorable, it should be remembered that most of the Bavarian railways are single lines, that a considerable length of the State railways is laid on stone-blocks, and with heavy gradients and sharp curves; also that the traffic on the main lines consists principally of heavy goods trains, as, for instance, on the single line from Nurnberg to Wurzburg, which forms part of the through route between Cologne and Vienna, and where there is a daily traffic of 144 engines and 1,360 wagon-axles. Here, since 1871, have been laid the steel-headed rails, at the most trying places, viz., on gradients of 1 in 100; and up to the present time not a single rail has been renewed. The number and date of laying are:

1871	556 rails.
1872	1,906 "
1873	1,518 "
Total	3 980 "

The steel-headed rails for the Bavarian State railways weigh 75.3 lbs. per yard, and are rolled in lengths of 19.7 feet, and 20.4 feet.

Where the failures have occurred it has been generally at those parts of the line where blocks are in use. Where sleepers are laid the renewals have been inconsiderable.

EFFECTS OF STRESS ON MAGNETIZATION OF STEEL AND IRON.

By Prof. Sir W. THOMSON, LL. D., F. R. S.

Proceedings of the Royal Society.

Weber's method, by aid of electromagnetic induction and a "ballistic galvanometer" to measure it, which has been practised with so much success by Thalén, Roland, and others, has been used in the investigation of which the results are at present communicated; but partial trials have been made by the direct magnetometric method (deflections of a needle), and this method is kept in view for testing slow changes of magnetization which the electromagnetic method fails to detect.

The metals experimented on have been steel pianoforte-wire, of the kind used for deep-sea soundings by the American Navy and British cable-ships; and soft-iron wires of about the same gauge, but of several different qualities.

I. *Steel.*

The steel wire weighs about 14½ lbs. per nautical mile and bears 230 lbs. Weights of from 28 lbs. to 112 lbs. were hung on it and taken off, and results described shortly as follows were found:

(1) The magnetization is diminished by hanging on weights, and increased by taking the weights off, when the magnetizing current is kept flowing.

(2) The residual magnetism remaining after the current is stopped is also diminished by hanging on the weights, and increased by taking them off.

(3) The absolute amount of the difference of magnetization produced by putting on and taking off weights is greater with the mere residual magnetism when the current is stopped than with the whole magnetism when the magnetizing current is kept flowing.

(4) The change of magnetization produced by making the magnetizing current always in one direction and stopping it is greater with the weights on than off.

(5) After the magnetizing current has been made in either direction and stopped, the effect of making it in the reverse direction is less with the weights on than off.

(6) The difference announced in (5) is a much greater difference than that in the opposite direction between the effects of stopping the current with weights on and weights off, announced in (4).

(7) When the current is suddenly reversed, the magnetic effect is less with the weights on than with the weights off.

II. *Soft-Iron Wires.*

Wires of about the same gauge as the steel were used, but, except one of them, bore only about 28 lbs. instead of 230. All of three or four kinds tried agreed with the steel in (1).

The first tried behaved (except a seeming anomaly, hitherto unexplained) in the reverse manner to steel in respect to (2), (4), (5), and (6); it agreed with the steel in respect to (7). Another iron wire*, which, though called "soft," was much less soft than the first, agreed with steel in respect to (1) and (2), but [differing from steel in respect to (3)] showed greater effects of weights on and off when the magnetizing current was flowing than when it was stopped.

Other soft-iron wires which were very

* It was tested magnetically with weights up to 56 lbs., and broke, unfairly however, when 63 lbs. were hung on.

soft, softer even than the first, agreed with all the steel and iron wires in respect to (1), but gave results when tested for (2), which proved an exceedingly transient character of the residual magnetism, and were otherwise seemingly anomalous.

The investigation is being continued with special arrangements to find the explanation of these apparent anomalies, and with the further object of ascertaining in absolute measure the amounts of all the proved effects at different temperatures up to 100° Cent.

THE EVAPORATIVE PERFORMANCE OF STEAM BOILERS.

By D. KINNEAR CLARK, M. Inst. C. E.

Transactions of the Institution of Civil Engineers.

The Author, in 1852, deduced, from a large number of experiments and observations made by himself and by others on locomotive-boilers using coke, that, assuming throughout a constant efficiency of the fuel, or proportion of water evaporated to the fuel, the evaporative performance of a locomotive-boiler, or the quantity of water which it was capable of evaporating per hour, *decreases* directly as the grate-area is increased: that is to say, the larger the grate the smaller is the evaporation of water, at the same rate of efficiency of fuel, even with the same heating surface. 2d, That the evaporative performance *increases* directly as the square of the heating surface, with the same area of grate, and efficiency of fuel. 3d, The necessary heating surface *increases* directly as the square root of the performance; that is to say, for example, for four times the performance of water evaporated, with the same efficiency, twice the heating surface only is required. 4th, The necessary heating surface *increases* directly as the square root of the grate, with the same efficiency: that is to say, for instance, if the grate be enlarged to four times its first area, twice the heating surface would be required for the same evaporative performance, with the same efficiency of fuel.

Let W be the quantity of water evaporated per hour, and C the weight of coke consumed per hour, W and C varying so as to preserve a constant ratio to each other; let $h=$ the heating surface, and $g=$ the area of grate in square feet; then

$$W = m\frac{h^2}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which m is a constant. When the water, W, is expressed in cubic feet, and nine lbs. of water are evaporated per lb. of fuel, the value of m, deduced from the results of forty experiments, was .00222; and

$$W = .00222\frac{h^2}{g}. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Reducing the standard of one square foot of grate, let w and c be the weights of the coal and the water respectively per square foot of grate, in constant ratio to each other; then, dividing the above formulæ respectively by g,

$$w = m\left(\frac{h}{g}\right)^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{and} \quad w \text{ (cubic feet)} = .00222 \left(\frac{h}{g}\right)^2 \quad . \quad (4)$$

showing that, when the ratio of the water to the fuel, or the efficiency of the fuel, is constant, the performance of the boiler per square foot of grate increases as the square of the ratio of the heating surface to the grate-area; or, in brief, as the square of the surface-ratio.

The following table of examples, extracted from "Railway Machinery," shows how close the evaporation proceeded according to the square of the surface-ratio, when 9 lbs. of water, at the ordinary temperatures and pressures, were evaporated per lb. of coke:

(*See Table on following page.*)

It was thus found that, practically, there can never be too much heating surface as regards economical evaporation, but there may by too little; and that, on the contrary, there may be too much grate-area for economical evaporation, but there cannot be too little, so long as the

RELATIVE HEATING SURFACES AND RATES OF CONSUMPTION OF WATER IN LOCOMOTIVE-BOILERS.

Classified Groups of Locomotives.	Surface-ratio.	Consumption of Water per hour per square foot of Grate.	Water per lb. of Coke.	Number of Experiments.
	Ratio.	Cubic feet.	lbs.	
E. & G. Railway	52	6.15	9.0	13
C. R. Passenger Engines	66	8.0	9.1	17
L. & S. W. Railway	72	12.0	8.9	2
Sphynx, A, Hercules	90	18.0	8.92	8

required rate of combustion per square foot does not exceed the limits imposed by physical conditions.

EXPERIMENTAL DEDUCTIONS OF M. PAUL HAVREZ, 1874.

That the evaporative performance of similar boilers per unit of grate-area increases with the square of the surface ratio, is confirmed by the deduction by M. Paul Havrez of the following law, from the performances of locomotive boilers: That the quantities of water evaporated by consecutive equal lengths of flue-tubes decrease in geometrical progression, whilst the distances from the commencement of the series increase in arithmetical progression. The point, he adds, at which the law begins to prevail, is that at which the radiation of heat from the fuel ceases, and heat is communicated by conduction alone. One of the experiments, of which the results were investigated by M. Havrez, was made by M. Pétiet, of the Northern Railway of France, who repeated the experiment of Mr. Woods and Mr. Dewrance, and tested the evaporative value of the different parts of a locomotive-boiler, having tubes of a length of twelve feet three inches, divided into five compartments. The first compartment consisted of the fire-box, with three inches of length of the tubes; the four tube sections were 3.02 feet long. Using coke and briquettes as fuel, the average results were as follows:

	Fire-box Section.	1st Tube Section.	2d Tube Section.	3d Tube Section.	4th Tube Section.
Surface	60.28 box. 16.15 tubes. 76.43	179	179	179	179 square feet.
Water evaporated per sq. ft. per hour with coke	24.5	8.72	4.42	2.52	1.68 pounds.
Do. do. with briquettes	36.9	11.44	5.72	3.52	2.31 "

M. Havrez's law of progression is traceable here; and whether it be exact or only approximately true, the rapidly diminishing evaporations are corroborative of the results of previous experiments.

If the successive evaporations be set off as ordinates to a base-line representing the advance of the heating surface, and contoured, the area of the figure is a measure of the total evaporation. The area would bulk largely at the first part, whence it would fall rapidly, and taper more slowly towards the end; and it is easily comprehended that such areas of evaporation, for boilers of different total lengths or quantities of surface, would increase practically as the squares of the total surfaces, supposing that the final temperatures of the gases on leaving the boilers were the same.

GENERAL RELATIONS OF GRATE-AREA, HEATING SURFACE, WATER, AND FUEL.

It is well known that, in a given boiler in which the grate and the heating surface are constant—and, of course, also the ratio of the surface to the grate-area—the greater the quantity of fuel consumed per hour, the greater also is the quantity of water evaporated; but that the production of steam increases at a less rate than the combustion: in other words, that the quantity of water evaporated per lb. of fuel is diminished. But it has remained a question—at which rate does this diminution of efficiency take place? The answer is supplied by the fact, generalized from experimental observations on stationary, portable, marine, and locomotive boilers, that the quantity of water evaporated per square foot of grate is expressed by a constant quantity, A, plus a constant multiple, B c, of the fuel consumed per square foot of grate; or by the general formula

$$w = A + B c \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The sense of this equation is that, though the proportion of the water evaporated per square foot of grate does not keep pace with the fuel consumed, yet that the quantity of water increases by equal increments for equal increments of fuel per square foot of grate.

To co-relate this formula (5), in which the surface-ratio is constant, with the formula (4), in which the evaporative efficiency of fuel is constant, it may suffice for the present to observe that the quantity B c is constant for all surface-ratios, and that the quantity A varies as the square of the surface-ratio. Let the surface ratio $\frac{h}{g} = r$, then $A = ar^2$, in which a is a constant which is specified for each kind of boiler; and

$$w = ar^2 + B c \quad . \quad . \quad . \quad . \quad . \quad (6)$$

w = the water evaporated in lbs. per square foot of grate per hour;

c = the fuel consumed in lbs. per foot of grate per hour;

$E = \frac{w}{c}$, the efficiency of the fuel, or the weight of water evaporated per lb. of fuel;

$A = ar^2$ = a constant, specific for each kind of boiler;

B = a constant multiplier, specific for each kind of boiler;

$r = \frac{h}{g}$ = the ratio of the heating surface to the grate-area; or the surface-ratio;

a = a constant, specific for each kind of boiler.

When the consumption of water and fuel per square foot of grate per hour is given, the value of the required surface-ratio is found from the above formula, for $ar^2 = w - B c$, and

$$r = \sqrt{\frac{w - B c}{a}} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

When the consumption of water per square foot of grate per hour, and the surface-ratio, are given; to find the amount of fuel per square foot of grate per hour required to evaporate the water; $B c = w - ar^2$, and

$$c = \frac{w - ar^2}{B} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

When the efficiency, E, $= \frac{w}{c}$, of the fuel is given—that is, the weight of water evaporated per lb. of fuel—also the surface ratio; to find the fuel that may be consumed per square foot of grate per hour corresponding to that efficiency. As $\frac{w}{c} = E = \frac{ar^2 + Bc}{c} = B + \frac{ar^2}{c}$; then $ar^2 = c\,(E - B)$; and

$$c = \frac{ar^2}{E - B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

When the efficiency, E, $= \frac{w}{c}$, and the fuel consumed per square foot of grate per hour, are given; to find the surface-ratio required to effect that evaporation. Since $ar^2 = c(E - B)$, and $r^2 = \frac{c(E - B)}{a}$,

$$r = \sqrt{\frac{c\,(E. - B)}{a}} \quad . \quad . \quad . \quad . \quad (10)$$

Evaporative Performance of South Lancashire Coal in three Experimental Stationary Boilers at Wigan. 1866–68.

The coal selected for trial was Hindley Yard coal, from Trafford pit, which ranks with the best coals of the district. Three stationary boilers were selected: 1. An ordinary double-flue Lancashire boiler, 7 feet in diameter and 28 feet long; two flue-tubes, 2 feet 7½ inches in diameter inside, of $\frac{3}{8}$-inch plate. 2. Another Lancashire boiler of the same dimensions, but with tubes of $\frac{5}{16}$-inch steel plate. 3. A Galloway or water-tube boiler, 26 feet long and 6 feet 6 inches in diameter, with two furnace-tubes 2 feet 7$\frac{5}{8}$ inches in diameter, opening into an oval flue, 5 feet wide by 2 feet 6$\frac{1}{2}$ inches high, containing twenty-four vertical conical water-tubes. These three boilers were set side by side, on side walls, and with two dampers. The flame passed through the flue-tubes, back under the boiler, then along the sides to the chimney. The chimney was 105 feet high above the floor, octagonal, 6 feet 10 inches wide at the base and 5 feet wide at the top, where the sectional area was 21 square feet.

	ft. long.	sq. ft.
Total grate-area in each boiler..	6	31.5
Total grate-area in each boiler..	4	21.0

	Lancashire.	Galloway.
Heating surface:	sq. ft.	sq. ft.
In flue tubes............	464.34	431.12
In external flues.........	303.08	288.24
Total surface...........	767.42	719.36
Ratio of grate-area, 6 feet long, to heating surface.	1 to 24.4	1 to 22.8
Ratio of grate-area, 4 feet long, to heating surface.	1 to 36.5	1 to 34.3

Circuit, or length of heating surface traversed by the draft from the center of the grate...............	80 feet	74 feet.
Total distance from center of grate to base of chimney..................	117 feet	101 feet.
Height of chimney above level of floor...........	100 feet	
Height of chimney above level of grates.........	96 feet 9 inches.	

The standard fire adopted for trial was 12 inches thick, of round coal, treated on the coking system, with a little air admitted above the grate for a minute or so after charging. The water was evaporated under atmospheric pressure.

The data afforded by these typical boilers are specially useful, as they represent classes of boilers in general use in England. The several experimental results, required for the present purpose, are collected in the annexed table. The first two results are for flash-drafts, in which the side and bottom flues were cut off, and the gases were conducted direct to the chimney after having passed through the fire-tubes. By plotting the coal and the water reduced according to the square of the

WIGAN STATIONARY BOILERS. RELATIONS OF COAL AND WATER.

Varying grate-area and surface-ratio. Calculations for surface ratio 30, by formula (13).

Boiler (without Economizer).	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour.		Water per square foot of Grate per hour, for surface-ratio, 30.		
			Actual.	Reduced in the ratio of the squares of the surface-ratios for ratio 30.	Reduced in the same ratio.	Calculated from column 5 by formula (13).	Difference by formula.
	Sq. feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Pr. cent.
Galloway, flue-tubes only.....	31.5	13.70	18.58	89.10	757.3	871.8	+15.0
Lancashire, flue-tubes only....	"	14.74	19.91	82.47	678.8	808.4	+19.0
Galloway, complete	"	22.8	18.30	31.68	322.9	322.9	0.0
Lancashire & Galloway.......	"	23.5	14.00	22.82	230.4	238.2	+ 3.4
Lancashire................ ..	"	24.4	17.26	26.03	271.5	268.8	− 1.0
"	"	"	18.60	28.12	290.2	288.8	− 0.5
"	"	"	19.10	28.87	293.7	296.0	+ 0.8
Lancashire, with water-tubes..	"	25.4	16.71	23.31	251.0	242.8	− 3.3
Galloway....................	21.0	34.3	21.80	16.68	179.6	179.5	0.0
Lancashire & Galloway.......	"	35.5	23.00	16.43	179.2	177.1	− 1.2
Lancashire........	"	36.5	21.50	14.52	158.0	158.8	+ 0.5
"	"	"	22.70	15.33	165.1	166.6	+ 0.9

surface-ratios, for a uniform ratio of 30, this formula was obtained:*

$$w = 20 + 9.56c \quad . \quad . \quad . \quad . \quad . \quad (13)$$

And, in the general form, for various ratios:

$$w = .0222r^2 + 9.56c \quad . \quad . \quad . \quad (14)$$

By the formula (13), the quantities of water in column 7 of the table were calculated from the reduced coals in column 5.

COMPARATIVE EVAPORATIVE PERFORMANCE OF STATIONARY BOILERS IN FRANCE. 1874.

An abstract of the Report on the trials of boilers of three types—the "Fairbairn," as it was called, the Lancashire, and the French or elephant boiler—has already been published in the Proceedings, to which reference is now made for particulars. The proportions and the results, with Ronchamp coal, are treated in the following table. The following special formulæ have been deduced for the three boilers respectively, and for the three collectively: †

"Fairbairn" $w = .01143r^2 + 7.7c$ . . (17)
Lancashire $w = .01126r^2 + 8.0c$ . . (18)
French $w = .01126r^2 + 8.0c$ . . (19)
All the boilers $w = .0111r^2 + 7.82c$. (20)

It is seen that the same formula applies to the Lancashire and the French boilers, and that, therefore, the reporters of the trials were justified in asserting that these boilers were equally efficient. The comparatively inferior quantity evaporated in the first trial in the table, resulted probably from an excessively large surplus of air admitted into the furnace. The total quantity of air, in that instance, amounted to 261 cubic feet per lb. of coal.

EVAPORATIVE PERFORMANCE OF LOCOMOTIVE-BOILERS.

The Author has collected from various trustworthy sources, the results of the performance of locomotive-boilers of the earliest as well as the most recent designs. Boilers of nearly every size and variety that have been used in England are represented in the tables. The areas of grate vary from 6 to 24 square feet, the heating surfaces from 40 to 2,000 square feet, and the ratios of surface to grate from 40 to 1, to 100 to 1. The fuel was coke, except in a few instances of boilers designed for burning coal, in which coal was used.

These experimental trials have been conducted under various conditions. There is, nevertheless, a remarkable

STATIONARY BOILERS IN FRANCE. RELATIONS OF COAL AND WATER.

Calculations of evaporative performance for surface-ratio 30; Ronchamp coal.

Boilers.	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour. Actual.	Coal per square foot of Grate per hour. Reduced in the ratio of the square of the surface-ratios for ratio 30.	Water per square foot of Grate per hour for surface-ratio 30. Reduced in the same ratio.	Water per square foot of Grate per hour for surface-ratio 30. Calculated from column 5 by formulæ (17), (18), (19).	Water per square foot of Grate per hour for surface-ratio 30. Difference by formula.
	Sq. feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
"Fairbairn"	20.5	49.5	10.70	3.93	34.8	40.70	+17.0
"	"	"	18.53	6.81	62.7	63.30	+ 0.9
Lancashire.	"	29.8	10.41	10.55	94.1	92.50	− 1.7
"	"	"	19.15	19.41	165.0	161.80	− 1.9
"	"	"	19.50	19.76	166.8	164.50	− 1.4
French.....	20.1	30.3	11.36	11.14	95.5	9.71	+ 1.7
"	"	"	19.87	19.48	165.4	162.30	− 1.9
"	"	"	20.57	20.16	166.6	167.60	+ 0.6

* Some experiments with a marine boiler at Newcastle gave

$$w = 25 + 9.71c \quad . \quad . \quad . \quad . \quad (11)$$
$$w = .02156r^2 + 9.71c \quad . \quad . \quad (12)$$

Details omitted here.

† Formulas 15 and 16 omitted above were deduced from a trial of English coals at Wigan. They are:

$$w = 25 + 10.75c \quad . \quad . \quad . \quad . \quad (15)$$
$$w = .01r^2 + 10.75c \quad . \quad . \quad . \quad (16)$$

degree of harmony amongst them; for, when plotted, they are seen, with a few exceptions of early date, to follow the laws of evaporative performance already enunciated. Even the performance of the boiler of the primitive Killingworth engine, when the evaporative efficiency is increased by one-half to represent the value of coke compared with coal as imperfectly burned in that boiler, ranges as well as should have been expected with those of other locomotives; in fact, the improved Killingworth boiler exhibits a performance above the average.

Using good coke as fuel, the evaporative performance of locomotive-boilers, in which the flue-tubes are spaced sufficiently apart to admit of a free circulation of water around them, is substantially embraced by the following formula, when the surface-ratio is 75, which is a good practical ratio:

$$w = 100 + 7.94c \text{ (coke)} \quad . \quad . \quad (21)$$

For any given surface-ratio, the general formula is

$$w = .0178r^2 + 7.94c \text{ (coke)} \quad . \quad (22)$$

Using good coal as fuel—Griff, Staveley, Hartley's, and coking coal from Newcastle—the formulæ for the coal-burning locomotive-boilers of the South-Eastern and London and South-Western Railways are:

S. E. Ry. L. & S. W. Ry.

For surface-ratio 75 $w = 50 + 9.6c$

$$w + 50 + 9.82c \quad . \quad (23)$$

For any surface-ratio $w = .009r^2 + 9.6c$

$$w = .009r^2 + 9.82c \quad (24)$$

Evaporative Performance of Portable Steam-engine Boilers. 1872.

The results of the excellently-conducted trials of portable steam-engines exhibited at the Show of the Royal Agricultural Society at Cardiff, in 1872, were fully reported by the Judges, Mr. F. J. Bramwell and Mr. Menelaus. To this valuable Report, with the tables appended to it, prepared by the Consulting Engineers, Messrs. Eastons and Anderson, the Author is indebted for the data with which he has formed the following Table:

Portable Steam Engine Boilers. Proportions and Results of Evaporative Performance, 1872.

(From the Report of the Judges, Royal Agricultural Society's Show, Cardiff.)

Fuel: Llangennech (Welsh) Coal.

No.	Constructors.	Area of Fire-grate. Normal.	Area of Fire-grate. As reduced for Trial.	Heating Surface (Tubes measured on outside).	Ratio of Heat'g Surface to Trial Fire-grate.	Coal consumed per square foot of Grate per hour	Equivalent Water evaporated from and at 212° Fahr. per square foot of Grate per hour.		Equivalent Water evaporated per lb. of Coal.
		Sq. ft.	Sq. ft.	Sq. feet.	Ratio.	lbs.	lbs.	Cub. ft.	lbs.
1	Marshall, Sons & Co...	4.4	3.0	283.5	94.5	15.7	161	2.58	10.23
2	Clayton & Shuttleworth	5.3	3.2	220.0	69	12.8	151	2.42	11.83
	"	"	"	"	"	12.5	148	2.36	11.81
3	Hayes................	5.1	5.1	170.6	33	14.8	66.5	1.06	4.59
4	Davey, Paxman & Co..	3.75	3.75	168.4	45	10.3	114	1.83	11.02
5	Tuxford & Sons.......	6.13	..	193.0	..	..	..	..	..
6	Brown & May........	3.2	3.2	159.1	50	9.53	104	1.66	10.89
7	Tasker & Sons...	4.7	4.7	158.0	34	13.0	119	1.91	9.33
8	Reading Iron Works...	7.2	2.37	211.0	89	20.4	214	3.43	10.49
9	Lewin	4.3	1.6	151.6	..	..	..	..	..
10	E. R. & F. Turner.....	3.5	3.5	187.8	54	20.7	204	3.26	9.93
11	Barrows & Stewart....	5.0	5.0	129.8	26	13.6	120	1.93	8.97
12	Ashby, Jeffery & Luke.	5.5	2.0	204.5	102	31.1	319	5.10	9.27

The fuel was Llangennech (Welsh) coal. The average quantity of ash and clinker was, as far as it was observed, about 6 per cent. of the fuel. The boilers were of the ordinary pattern, having a fire-box and multitubular flues; but Messrs. Davey, Paxman, & Co.'s boiler contained, in addition, ten circulating wrought-iron bent water-tubes, $2\frac{1}{4}$ inches in diameter in the fire-box, rising from the sides to the top.

These boilers are arranged in the

annexed table, in the order of the surface-ratios. The coal and the water per square foot of grate are reduced for the ratio 50 (columns 5, 6), from which has been deduced, by plotting, the formula

$$w=20+8.6c \quad . \quad . \quad . \quad . \quad . \quad (25)$$

For any given surface-ratio the general formula is

$$w=.008r^2+8.6c \quad . \quad . \quad . \quad . \quad (26)$$

The calculated quantities of water (column 7) by formula (25) follow closely the reduced quantities (column 6), except in the first three instances, Nos. 12, 1, and 8, where they are much in excess. In these instances, the excessive reduction of the grate has involved a material departure from the normal disposition of a fire-box, especially for No. 8, in which the grate was reduced to a third of its normal area, and the surface-ratios were driven up to 102, 94.5, and 89; and the first two boilers, Nos. 12 and 1, have the greatest number and the smallest diameters of tubes. The drift of the evidence goes to show that fewer tubes, of larger diameter, do better for the combustion of coal, the circulation of water, and the absorption of heat.

There is another exceptional boiler, No. 3, with a surface-ratio 33, in which the calculated quantity of water is twice as much as the reduced actual quantity. The excess, in this case, is satisfactorily accounted for by causes which were pointed out by the Judges in their reports. They stated that the boiler only did half its duty—an affirmation which is precisely confirmed by the tabulated calculation.

Portable Engine Boilers. Relations of Coal and Water.

Calculations of evaporative performance for surface-ratio 50.

No. of Boiler.	Grate-area as reduced for Trial.	Surface-ratios.	Coal per square foot of Grate per hour. Actual.	Coal per square foot of Grate per hour. Reduced in the ratio of the squares of the surface-ratios for ratio 50.	Water per square foot of Grate per hour for Surface-ratio, 50. Reduced in the same ratio as for the Coal.	Water per square foot of Grate per hour for Surface-ratio, 50. Calculated from column 5 by formula (25).	Water per square foot of Grate per hour for Surface-ratio, 50. Difference by formula.
	Square feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
12	2.00	102.0	31.10	7.473	69.28	84.27	+ 21.6
1	3.00	94.5	15.70	4.395	44.96	57.80	+ 28.5
8	2.37	89.0	20.40	5.73	60.11	69.38	+ 15.2
2	3.20	69.0	12.80	6.721	79.51	77.80	− 2.1
"	"	"	12.50	6.564	77.52	76.45	− 1.4
10	3.50	54.0	20.70	17.75	176.20	172.60	− 2.0
6	3.20	50.0	9.53	9.53	103.80	102.00	− 1.7
4	3.75	45.0	10.32	12.72	140.10	129.40	− 7.6
7	4.70	34.0	13.00	28.11	262.30	261.70	− 0.2
3	5.10	33.0	14.80	33.97	155.90	312.10	+100.0
11	5.00	26.0	13.60	50.30	451.10	452.60	+ 0.3

Looking to the evaporating capabilities of the portable-engine boilers in their ordinary condition, with unrestricted grates, it may be useful to show at what rates they are capable of evaporating water from and at 212°, in the ratio of 10 lbs. of water per lb. of coal consumed. For the calculation of these rates, the formula (9), may be employed. It is

$$c=\frac{ar^2}{E-B} \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

The value of E is 10; of B is 8.6; and of a is .008; and, by substitution,

$$c=\frac{.008r^2}{10-8.6}\text{; or}$$

$$c=\frac{.008r^2}{1.4} \quad . \quad . \quad . \quad . \quad . \quad (28)$$

By this formula, the value of c, the quantity of coal consumed per square foot of grate per hour, is found, when the surface ratio, r, is given for each boiler.

Thence, multiplying by the grate-area, is found the total quantity of coal per hour; and ten times the coal is the quantity of water. In this way the following table is calculated in which the boilers are placed in the order of their normal surface-ratios. It is seen that No. 2 boiler is capable of evaporating at the given rate of efficiency, 8.15, say 8, cubic feet of water per hour. This is just 1 cubic foot per nominal HP., all the boilers having been designated of 8 HP. No. 11 boiler would only evaporate 3 cubic feet per hour, at the given rate of efficiency; whilst No. 1 is capable, by the calculation, of evaporating 16½ cubic feet per hour. It has already been seen that there is reason, in the design of its tube-surface, for doubting whether No. 1 is capable of so good a performance.

From the last line of the table, it may be assumed that the standard of average practice for portable-engine boilers of 8 nominal HP., is based on the following data, taken in round numbers:

Nominal HP..........	8 HP.
Area of fire-grate.......	5.5 square feet.
Area of heating surface.	220.0 "
Ratio of heating surface to grate-area, or surface-ratio...........	40 to 1.
Coal of good quality consumed per hour......	50 lbs.
Coal of good quality consumed per HP.......	6.25 lbs.
Coal of good quality consumed per square foot of grate, say.........	9 lbs.
Water evaporated, from and at 212° Fahr., per hour, at the rate of 10 lbs. per lb. of coal....	500 lbs. or 8 cub. ft.
" " per HP	62.4 lbs. or 1 "
" " per sq. foot of grate, 91 lbs. say..................	90 lbs. or 1.45

PORTABLE ENGINE BOILERS. CALCULATED EVAPORATIVE PERFORMANCE.

From and at 212° Fahr., at the rate of 10 lbs. of water per lb. of coal.

No. of Boiler.	Surface-ratio.	Grate-area.	Coal consumed per hour.		Total water evaporated per hour.	
			Per square foot of Grate	Total.		
	Ratio.	Sq. feet.	lbs.	lbs.	lbs.	Cubic feet.
2	64	4.40	23.40	102.96	1,029.6	16.50
10	54	3.50	16.66	58.31	583.1	9.34
6	50	3.20	14.30	45.76	457.6	7.33
4	45	3.75	11.57	43.24	432.4	6.93
2	41	5.30	9.60	50.88	508.8	8.15
12	37	5.50	7.82	43.01	430.1	6.89
9	35	4.30	7.00	30.10	301.0	4.82
7	34	4.70	6.60	31.02	310.2	4.97
3	33	5.10	6.22	31.72	317.2	5.08
5	31	6.13	5.50	33.71	337.1	5.40
8	29	7.20	4.23	30.45	304.5	4.88
11	26	5.00	3.86	19.30	193.0	3.09
Averages..........	40	4.84	9.14	44.24	442.4	7.09
To evaporate 8 cubic feet of water per hour	40	5.46	9.14	49.92	499.2	8.0

GENERAL FORMULÆ FOR PRACTICAL USE.

In the French experiments with stationary boilers, the Lancashire and French boilers were, by the formulæ (17 to 20) identical in performance; and the so-called "Fairbairn" boiler was within 3½ per cent. as effective as these. The three forms of boiler may therefore be accepted as equally efficient; and they may be classed with the Wigan boiler, as of equal efficiency, with coal of equal quality, and with equally good management.

The performance of the Howard boiler, as reported, is conformable to the formula for the Wigan boiler; and the Howard boiler is a type of the "sectional" kind of boilers.

The formula for the Wigan boiler is therefore applicable to all stationary boilers other than multitubular, with best coal and good management.

The performances of the Newcastle and Wigan marine boilers are nearly alike. Thus for a surface-ratio 30, the corresponding quantities of water, w, for different rates of coal, c, per square foot of grate per hour, are as follows:

					lbs.
Coal	$c=$	10,	20,	30,	40
Newcastle boiler	$w=$	116.5,	213.6,	310.7,	407.8
Wigan boiler	$w=$	116.5,	224.0,	331.5,	439.0
Differences	$w=$	0.0,	10.4,	20.8,	31.2
					per cent.
Less than Wigan	$w=$	0.0,	4.6,	6.3,	7.1

Halve the differences, and so take a mean of the formulæ; this will give a satisfactory general formula for marine boilers:

Newcastle . $w=.02156r^2+9.71c$
Wigan . . $w=.01r^2+10.75c$

Mean, $w=.016r^2+10.25c$. (29)

For coal-burning locomotive boilers, a mean of the two formulæ adduced, which are nearly identical, will be a satisfactory formula:

S. E. Ry. . . $w=.009r^2+9.6c$
L. & S. W. Ry. $w=.009r^2+9.82c$

Mean $w=.009r^2+9.7c$ . . (30)

The general formulæ which have been deduced are here collected together:

Formulæ for the Relation of Coal and Water consumed in Steam Boilers, per square foot of Grate-area per hour; and the Ratio of the Heating Surface to the Area of the Fire-grate.

Stationary boilers .	$w=.0222r^2+9.56c$	(31)
Marine boilers . .	$w=.016r^2+10.25c$	(32)
Portable-engine boilers	$w=.008r^2+8.6c$.	(33)
Locomotive-boilers (coal-burning) .	$w=.009r^2+9.7c$.	(34)
Locomotive-boilers (coke-burning) .	$w=.0178r^2+7.94c$.	(35)

Limits to the Application of the Formulæ (31) to (35).

There are minimum rates of consumption of fuel below to which these formulæ are not applicable. The limit varies for each kind of boiler, and it varies with the surface-ratio. It is imposed by the fact that the maximum evaporative power of fuel is a fixed quantity, and is naturally at that point of the scale where the reduction of the rate of combustion for a given ratio procures the absorption into the boiler of the whole of the heat which is available for evaporation. In the combustion of good coal, the limit of evaporative efficiency may be measured by 12½ lbs. of water from and at 212° Fahr.; and in that of good coke, by 12 lbs. of water from and at 212° Fahr.

To ascertain the minimum rates of combustion of coal for stationary boilers, to which the formula (31) applies: the limit is reached when w becomes equal to $12.5c$; or when $12c=.0222r^2+9.56c$, or $.0222r^2=(12-9.56)\ c=2.94c$. By reduction, $c=\frac{.0222}{2.94}r^2=.00755r^2$. For a given surface-ratio, r, the limiting value of c is found by multiplying the square of the ratio by .00755.

For the other kinds of boiler, the limiting values of c are found in the same way. They are here placed all together:

Stationary boilers,
limiting value of $c=.00755r^2$
Marine boilers,
limiting value of $c=.007r^2$
Portable-engine boiler,
limiting value of $c=.002r^2$
Locomotive-boilers (coal-burning)
limiting value of $c=.00325r^2$
Locomotive-boilers (coke-burning)
limiting value of $c=.0044r^2$

For lower values of c, or consumptions of fuel per square foot of grate per hour, the values of w, the corresponding quantities of water, are simply $12.5c$ for coal, and $12c$ for coke.

The annexed table, contains the limiting values of c for given surface-ratios, r.

The only limit to the application of the formulæ (31) to (35), to ascending values of c, or quantities of fuel per square foot per hour, is the limit of endurance of the fuel itself under the action of the draft—from 100 lbs. to 120 lbs. per square foot per hour, for ordinary hard coal or coke. Beyond this limit, the fuel is liable to be shaken and partly dispersed, unconsumed, by the force of the draft; although coke has been known to withstand the draft of a locomotive, when consumed at the rate of 130 lbs. per square foot per hour.

Minimum Values of c, or Minimum Quantities of Fuel Consumed per Square Foot of Grate per Hour, for given Surface-Ratios, to which the Formulas (31) to (35) are Applicable.

	Surface-ratio.						
	5	10	15	20	30	40	50
	Minimum Consumption of Fuel per square foot of Grate per hour.						
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Stationary....................	.2	.7	1.7	3.0	6.8	12.1	18.9
Marine	.17	.7	1.6	2.8	6.3	11.2	17.5
Portable......................	.05	.2	.4	.8	1.8	3.2	5.0
Locomotive (coal-burning)	.1	.3	.7	1.3	2.9	5.2	8.1
Locomotive (coke-burning)....	.1	.4	1.0	1.8	4.0	7.0	11.0

	Surface-ratios—*continued*.					
	60	70	75	80	90	100
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Locomotive (coal-burning).....	11.7	15.9	18.3	20.8	26.3	32.5
Locomotive (coke-burning)....	16.0	21.0	25.0	28.0	36.0	44.0

Applications of the Formulæ for the Evaporative Performance of Steam Boilers.

The following Table contains the relative quantities of fuel consumed and water evaporated, for surface-ratios, and rates of combustion per square foot of grate per hour, within the range of ordinary practice. It is seen that, with the surface-ratios 30 and 50, the boilers are, in the order of evaporative efficiency, as follows:

Surface-ratio 30.

Marine.
Stationary.
Locomotive (coal-burning).
Portable.
Locomotive (coke-burning).

Surface-ratio 50.

Marine.
Stationary.
Locomotive (coal-burning).
Locomotive (coke-burning).
Portable.

Portable-engine boilers are clearly inferior in efficiency to coal-burning locomotive-boilers, and they may be constructed like these with sensible advantage.

(*See Table on following page.*)

Employment of the Formulae (31) to (35) for Fuels of inferior Heating Power.

To find the evaporative performance of a given quantity of inferior fuel per square foot of grate per hour: substitute for the given quantity the equivalent quantity of best coal, and find by the formula the water evaporated.

2. To find the quantity of an inferior fuel required for a given evaporative performance per square foot of grate per hour: find, by the formula in its inverted form, on the model of the equation (27), the quantity of best coal required, and substitute for this amount the equivalent quantity of the inferior fuel.

Evaporative Performance of Steam Boilers for Increasing Rates of Combustion and Different Surface-Ratios.

For Best Coal and Best Coke, Surface-ratio 30.

Kind of boiler and fuel.	Water from and at 212° Fahr. per hour.	Fuel per square foot of Grate per hour in lbs.						
		5	10	15	20	30	40	50
					Water.			
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Stationary Coal. Formula (31)	Per square foot	62.5	116	163	211	307	402	498
	per lb. of coal	12.5	11.56	10.89	10.56	10.23	10.06	9.96
Marine. Coal. Formula (32)	Per square foot	62.5	117	168	219	322	424	527
	Per lb. of coal	12.5	11.69	11.25	10.95	10.69	10.61	10.54
Portable. Coal. Formula (33)	Per square foot	50	93	136	179	265	351	437
	Per lb. of coal	10	9.3	9.01	8.95	8.83	8.77	8.74
Locomotive, Coal-burning Formula (34)	Per square foot	57	105	154	202	299	396	493
	Per lb. of coal	11.4	10.5	10.26	10.10	9.97	9.90	9.86
Locomotive, Coke-burning Formula (35)	Per square foot	56	95	135	175	254	334	413
	Per lb. of coke	11.14	9.54	9.02	8.75	8.47	8.35	8.03

Surface-ratio 50.

Kind of boiler and fuel.	Water from and at 212° Fahr. per hour.	5	10	15	20	30	40	50
Stationary. Coal. Formula (31)	Per square foot	62.5	125	187.5	247	342	438	534
	Per lb. of coal	12.5	12.5	12.5	12.33	11.41	10.95	10.67
Marine. Coal. Formula (32)	Per square foot	62.5	125	187.5	245	348	450	552
	Per lb. of coal	12.5	12.5	12.5	12.25	11.58	11.25	11.05
Portable. Coal. Formula (33)	Per square foot	62.5	106	149	192	278	364	450
	Per lb. of coal	12.5	10.6	9.93	9.6	9.27	9.10	9.00
Locomotive, Coal-burning Formula (34)	Per square foot	62.5	120	168	217	314	411	508
	Per lb. of coal	12.5	11.95	11.20	10.85	10.16	10.26	10.15
Locomotive, Coke burning Formula (35)	Per square foot	60	120	164	203	283	362	442
	Per lb. of coke	12.0	12.0	10.91	10.16	9.42	9.05	8.83

Surface-ratio 75.

Kind of boiler and fuel.	Water from and at 212° Fahr. per hour.	Fuel per square foot of Grate per hour in lbs.						
		30	40	50	60	75	90	100
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Locomotive, Coal-burning Formula (34)	Per square foot	342	439	536	633	778	927	1020
	Per lb. of coal	11.39	10.97	10.71	10.65	10.37	10.26	10.20
Locomotive, Coke-burning Formula (35)	Per square foot	338	418	497	576	695	815	894
	Per lb. of coke	11.27	10.44	9.94	9.61	9.26	9.05	8.94

NOTE.—In applying these rules, a heating power represented by an evaporation of 16 lbs. of water from and at 212° Fahr. may be taken as the standard for best coals, such as were employed in the trial of the Newcastle and Wigan boilers.

HEATING POWERS OF FUELS.

No.	Fuel.			Heating Power of 1 lb. of Fuel.	
				Units of Heat.	Water evaporated per lb. of Fuel from and at 212° Fahr.
				Units.	lbs.
1	Warlich's fuel			16,495	17.07
		Units.	lbs.		
	Coal: Ebbw Vale, 1848	16,221	16.79		
	Powell's Duffryn, 1848	15,715	16.25		
	Llangennech, 1848–71	14,765	15.28		
2	Average (best Welsh)	15,567	16.11	15,567	16.11
3	Haswell Wallsend (Newcastle)			15,502	16.04
4	British Coals, Average			14,123	14.63
5	Coke			13,550	14.02
6	Lignite, perfect			11,678	12.10
7	Asphalt			16,655	17.24
8	Wood, perfectly dry			7,792	8.07
9	Wood, 25 per cent. moisture			5,565	5.80
10	Wood-charcoal, dry			12,696	13.13
11	Peat, perfectly dry			9,951	10.30
12	Peat, 25 per cent. moisture			7,156	7.41
13	Peat-charcoal, 85 per cent. carbon, dry			12,325	12.76
14	Tan, perfectly dry, 15 per cent. ash			6,100	6.31
15	Tan, 30 per cent. moisture			4,284	4.44
16	Straw, 14¼ per cent. moisture (probably)			7,600	7.87
17	Petroleum			20,240	20.33
18	Petroleum oils			27,531	28.50
19	Coal gas, mean of Ross and Harcourt			34,292	35.50

THE BESSEMER SPECTRUM AND STEEL BLISTER.

From "Iron."

AT the last meeting of the Société de l'Industrie Minérale, at Saint-Etienne, M. Pourcel reported that a new fact in relation to the spectrum of the Bessemer flame has been observed by M. Legat, at the Saint-Etienne Steelworks, and verified at Terrenoire by M. Deshayes. In treating siliceous pig the complete spectrum of the Bessemer flame may be produced at will by throwing a few pieces of carbonate of lime into the crucible during the period of combustion of the silicon, or first period, as it is termed, during which flame never appears and the spectrum is absent. This phenomenon, easily explained by the decomposition of the carbonic acid of the limestone, supports the opinion which attributes the groups of green and red rays of the Bessemer spectrum to the combustion of carbonic oxide under pressure at a high temperature, not to the combustion of iron and manganese.

M. Meurgey asks if the spectrum lasts long, and M. Pourcel states that its duration is proportionate to the quantity of limestone used. Mr. Henry is unable to see why carbonic acid should be decomposed in this particular case and originate the spectrum. Mr. Snelus had analysed the gases given off at the Bessemer converter at different points of the operation, and found that a considerable quantity of carbonic acid was produced during the first period. Why should not this carbonic acid be decomposed in the usual course of working, and so give rise to the spectrum?

M. Pourcel replies that the gases which issue from the converter are produced by a preliminary reaction. It cannot be admitted that the carbonic acid in the gases produced during the first period are intimately mixed with the mass of melted metal, and then it cannot be decomposed. In treating siliceous pig, and during the first portion of the operation, the action of the silicon predominates. It is a more oxidisable body than carbon; consequently, the quantity of the latter, which burns simultaneously with the silicon by intermolecular combustion (not direct combustion), can only be infinitely small; the carbonic oxide which results is therefore engulfed in an excess of air, which peroxidises it instantaneously. Snelus' analyses prove the presence of free oxygen and of a quantity of carbonic acid which is but feeble compared with the whole volume of gas produced. In the particular case in question, on the contrary, the carbonic acid of the limestone thrown into the converter is intimately mixed with the melted metal; it is therefore admissible that the silicon decomposes it under the influence of a double affinity, that of silicon for oxygen, and silica for lime. The reaction appears vigorous, it almost instantly produces a very intense flame. Without doubt, the carbonic oxide liberated, coming in excess into the converter, as happens in the second period of the operation, no longer finds sufficient free oxygen to become totally transformed into carbonic acid; it therefore comes to the neck of the converter and burns at the expense of atmospheric oxygen.

If this explanation is not true, it looks at all events like truth. It admits that the silicon decomposes carbonic acid, which is plausible, since this gas is an oxidising agent, at a high temperature, which the iron itself decomposes. It is now known the reducing power of silicon goes farther, since the presence of this body prevents the formation of carbonic oxide. It is on this reaction that the Terrenoire process of making solid steel is based.

M. Devillaine, the chairman of the meeting, invites M. Pourcel to explain this a little.

Without losing sight of the object of the discussion, M. Pourcel can give some information on the subject of making steel without air-holes, the Terrenoire company being protected by very exhaustive patents. From the time that the different phases of the Bessemer operation were explained, the means of running steel without flaw was really discovered. It was known that silicon prevents the formation of carbonic oxide; the principle was thus established and all that was needful was to deduce the consequences and follow up their applications. It was analytic means which led, at Terrenoire, to the practical process of casting steel without flaw. The facts observed were as follows:—In the Martin furnace as we softened a gray siliceous pig by means of successive additions of iron and steel we found, by taking samples after each addition, that the metal run was honeycombed with air-holes. This being proved, if the solid sample taken immediately before the rotten sample be submitted to analysis, silicon is found in the metal which is free from honeycomb, while the honeycombed metal may contain intermingled slag, but no free silicon. Such is the analytic result, the effects of which can be reproduced synthetically. If we add silicon, in the form of silicide of iron, to a prepared steel bath, the air-holes will completely disappear. The steel, it is true, is generally red short; its shortness has been, and still is, attributed to the presence of silicon, not merely by steelmakers, but the greater number of our most eminent chemists. The explanation is admitted only provisionally by M. Pourcel, who now thinks it subject to discussion. His own opinion is, that the silicon does not deprive steel of any of its qualities, in the proportions in which it is usually found—that it neither makes it red short nor cold short.

Bessemer showed, some eight or ten years ago, that air-holes in cast steel are due to carbonic oxide originated in the liquid steel by an intermolecular reaction between the carbon of the metal and the ferric oxide formed during casting. If the metal remains liquid long enough the gases escape, but, generally speaking, the melting point of steel is but little higher than that of its solidification. The carbonic oxide thus remains imprisoned, and gives rise to air-holes, or silvery-looking cells, arranged symmetrically and perpendicularly to the greater axis of the ingot.

Silicon prevents the formation of these blisters, by reason of its being more oxidizable than carbon—by intermolecular combustion, of course—the oxidizing body being peroxide of iron or carbonic acid, or both; but then, instead of being a gas, the product of oxidation is a solid body, which originates in the mass of the metal, and is found uniformly distributed between its molecules. It is silicate of iron, it is slag interposed between its molecules which makes the metal red short and lowers its good qualities as a cast metal. The way to remove the slag is to add to it a base, which gives it fluidity. M. Pourcel uses manganese for this purpose, and herein is the principal point of the operation. Manganese, in the Bessemer process, serves to remove from the cast metal the peroxide of iron which it holds in solution; it reduces it to its minimum of oxidation, by taking an equivalent of its oxygen, and the union of the oxide of manganese with the silicate of iron gives a very fluid slag, which is liquated.

Troost and Hautefeuille, in the papers they have read before the Academy of Sciences, have confirmed this explanation of the action of the manganese added at the end of the Bessemer process, an explanation given by M. Valton, more than eight years ago, in a paper in the *Bulletin de l'industrie minérale.* The theory has now become practice, and practice fruitful in good results.

One of these has been deduced by M. Pourcel, who, for the silicide of iron, substitutes a double silicide of iron and manganese as the addition to a bath of steel meant to give unblistered metal. The two reducing bodies, silicon and manganese, act simultaneously on the melted mass to reduce the peroxide of iron and hinder the formation of oxide of carbon, and the result of their oxidation is a silicate of protoxide of iron and protoxide of manganese, very fluid at the temperature at which steel solidifies, and easily liquated. As to the silicide in excess, its effects are not harmful, M. Pourcel thinks. He is not able, he states, to relate the experiments on which they are based without going away from the subject under discussion, but they will, he hopes, be shortly laid before the society.

The principal manufacture described by M. Pourcel is simple to enounce, but difficult to carry out; the difficulties, however, have been in great part overcome, and at the Terrenoire Steel-works there is reproduced in cast steel almost every shade of difference recognizable in wrought iron, from the hardest to the mildest. The perfect homogeneity of these cast steels, resulting from their chemical composition and the perfect equilibrium of their molecules, produced by reheating or a varied tempering, are capable, in the opinion of M. Pourcel, of giving results which have never been obtained with forged steels.

In returning to the question of the Bessemer spectrum, M. Pourcel believed he had sufficiently proved that the addition of limestone to a siliceous pig treated in the Bessemer converter, may give rise to carbonic oxide during the period in which it is not produced normally, and he believes that the theory which attributes the complex spectrum of the Bessemer flame to the combustion of carbonic oxide at a high temperature under pressure is as defensible, in the present state of our knowledge of the phenomena of the spectrum, as that which attributes this spectrum to the combustion of iron and manganese.

M. Henry draws attention to the fact that Snelus' analyses prove that the quantity of carbon contained in the gases issuing from the converter attains its maximum towards the end of the operation, that is to say, at the moment when the spectrum fades and the yellow sodium ray alone continues; it is therefore surprising to see the effect diminish when the cause which engenders it, according to M. Pourcel's opinion, increases in intensity.

To this objection of M. Henry's, M. Pourcel opposes another. When the groups of red and green rays have disappeared from the spectrum, the intensity of the flame is decreasing, and the yellow sodium ray is alone continued; if we go on admitting air into the converter, the iron and the manganese are oxidised with such rapidity that a great quantity of the metal is cindered in a few seconds and the entire mass would be rapidly cindered if the refractory bottom of the converter, eaten out in two or three minutes by the oxide of iron, did not allow the metal and cinder to run into the pit. This is a particular case where, if the iron and manganese, the iron particularly, for the manganese would rapidly disappear, gave a spectrum in burning it would be easy to observe it; for the flame though feeble, on account of the small quantity of carbon left, still remains, and the yellow ray is visible to the end, that is to say, so long as blowing lasts. M. Pourcel concluded by saying that both opinions have their reasons, but neither had reasons which could be regarded as irrefutable, and the truth had probably yet to be discovered.

NOTES ON THE HYDRAULIC AND OTHER CEMENTS AT THE PHILADELPHIA EXHIBITION.

By Q. A. GILLMORE, Lieut.-Col. Engineers, Brevet-Major General, U. S. Army.

Written for Van Nostrand's Engineering Magazine.

PORTLAND CEMENT.

Portland cement may be produced by burning with a suitable heat, usually of an intensity and duration sufficient to induce incipient vitrification:

1. Certain argillaceous limestones, or
2. Certain calcareous clays, or
3. An artificial mixture of carbonate of lime and clay, or
4. An artificial mixture of caustic lime and clay.

The burnt product is reduced to powder by grinding.

These four methods of making this cement were all represented at the Exhibition, and will be briefly described.

First Method.—By this method the cement is produced by burning and grinding an argillaceous limestone containing from 77 to 80 per cent. of carbonate of lime, and 20 to 23 per cent. of clay. The stone should be a homogeneous and intimate mixture of the constituent ingredients, and the clay in it should contain at least 1½ to 2 parts of silica to one of alumina. There are generally present also carbonate of magnesia and oxide of iron in small quantities, and sometimes, and not injuriously, a small percentage of alkaline compounds, but not less than 94 per cent. of the essential ingredients—the carbonate of lime and clay—should be present, in order to yield a Portland cement of first quality. The presence of carbonate of magnesia becomes seriously objectionable when its amount exceeds 3 per cent. of the whole.

Only two localities are represented by this method of making Portland cement, viz: Teil in France, on the River Rhone, and Coplay in the United States, near Allentown, Pa. The Teil cement is the unslaked residium produced in manufacturing the siliceous hydraulic lime of Teil. It is burnt at a lower heat than any other Portland cement exhibited.

The Portland cement made at Coplay is produced from an argillaceous limestone, which has for several years been used in making the quick-setting cement of that locality. The stone contains in suitable proportions all the essential ingredients of unburnt Portland cement, but it is not an intimate and homogeneous mixture of those ingredients, and when broken into fragments and burnt at a high heat it yields a heterogeneous mixture containing Portland cement, common cement, caustic lime and hydraulic lime. In order to make Portland cement from it, it is first finely ground between mill stones, then tempered stiffly with water and formed into irregular shaped lumps or balls. These, after partial drying, are burnt in intermittent upright kilns, in layers alternating with layers of anthracite coal. The cement is known in the market as Saylor's Portland Cement.

At Seilley, in France, a small town only a few hours ride by rail from Paris, Portland cement was made, six years ago, by M. Francois Coignet, by a mode essentially the same as that pursued at Teil, but none of it was in the Philadelphia Exhibition, and I do not know whether the establishment is in operation at the present time or not, neither do I know of any locality except Teil and Sielley, in France, and Coplay, in the United States, where an argillaceous limestone is found, from which this grade of cement can be made without the addition of other materials.

Second Method.—Argillaceous chalk, or, as it is sometimes called, calcareous clay, of the same composition as the natural stone above mentioned, is used for making Portland cement by the second method, and either the wet process or the dry process may be followed. The wet process is the most common, and throughout Europe the prevailing custom is to burn it in layers alternating with gas coke, or anthracite coal, in an upright intermittent kiln.

The only locality known to furnish the material for making cement by this method is near Boulogne-Sur-Mer, France, where the extensive establishment of Messrs. Lonquéty & Co., is engaged in this business. The material is found in the inferior cretaceous formation, and consists of an argillaceous chalk, containing from 76 to 82 per cent. of carbonate of lime, and 18 to 24 per cent. of clay. The deposit is soft enough to be excavated with a pick and shovel, and it is manipulated by the wet process.

The *Third Method* consists in producing Portland cement by burning an artificial mixture of carbonate of lime and clay, and is specially applicable to localities where chalk or tender marl abounds. The hard compact limestone may also be used, although it must be borne in mind that the large consumption of power involved in the reduction of the hard carbonates to powder, places them under a disadvantage which practically excludes their employment in regions which supply chalk. Suitable clay is of more rare occurrence than suitable limestone, for the reason that the former must contain silica and alumina, not only in certain proportions, but in a certain state of comminution.

All the English Portland cements are made by the wet process, with a mixture of chalk—either white or grey—and clay procured from the shores or dredged from the bottom of the Medway or the Thames. The exhibitors were Francis & Co., Hollick & Co., A. H. Lavers, The Wouldham Cement Co., and Eastwood & Co., all of London. Eastwood & Co., exhibited briquettes of cement formed for testing, but none of the cement in powder.

The Scanian Cement Co., whose works at Lomma, near Malmö, Sweden, use cretaceous chalk and clay, operate by the wet process, and burn in upright kilns, with coke made on the spot from English coal.

The Wampum Cement & Lime Co., (limited) of New Castle, Lawrence Co., Penn., exhibited a cement made by the dry process from fossil limestone and clay, both being ground together in suitable proportions, and the mixture tempered with water, formed into bricks, dried in ovens, and then burnt in intermittent kilns.

Wm. McKay, of Ottawa, Canada, had on exhibition some patented cement made with a mixture of shell marl, clay, and a small percentage of carbonate of soda. It was prepared experimentally and has never been manufactured for market.

In the *Fourth Method* of making this cement, the carbonate of lime is burnt and slaked before the clay is added, and the proportions are correspondingly varied by making the proper allowance for the loss of weight by the first burning. The celebrated Vicat cement is produced by this method in France, by the wet process. A sample of it, informally exhibited by an importer, did not sustain its reputation for superiority to the average Portland cements made from carbonate of lime and clay, than which it usually commands a higher price in all markets regulated by intelligent discrimination with respect to quality.

The cement exhibited by Messrs. Toepffer, Grawitz & Co., of Stettin, Germany, made from an artificial mixture of lime and clay, justifies, by its excellence, this method of manufacture.

(It may be stated here that "The National Portland cement company of Kingston," has been organized for making this grade of cement at Kingston, Ulster Co., New York, on the bank of the Hudson River, the materials employed being fuller's earth, kaolin and lime. They are thoroughly ground and mixed together by the wet process, although much less water is employed in the manipulation, than in either the English works on the Thames, or in the works at Boulogne, France. Samples of this cement recently tested gave excellent results, as good indeed as those obtained with the best article on exhibition.)

Other Portland cements besides those above named, were in the exhibition, and were carefully examined and tested, but as no information was furnished with regard to kinds of materials used, and the methods followed in their manufacture, no special reference will be made to them here, except to give them their proper place in the accompanying table, which assigns to them their relative value.

It is hoped and believed that the manufacture of Portland cement in the United States, has taken such a start, that in a short time, possibly within a few months, very little if any of the foreign article will find a market here, except upon the Pacific Coast where it will be procured by direct importation.

THE NATURAL QUICK-SETTING CEMENTS.

The natural light, quick-setting cements, known also as Roman cements, are produced by burning at a comparatively low heat, not greatly exceeding in intensity and duration what would suffice to expel the carbolic acid, certain argillaceous or siliceous limestones, usually containing less than 77 per cent. of carbonate of lime, or argillo-magnesian limestones which contain less than 77 per cent. of both carbonates, and then grinding the product to a fine powder between millstones. They can be, and in Europe were formerly produced artificially by burning a mixture of lime, or of carbonate of lime and clay, before Portland cement became known by the discovery that with certain definite proportions of the ingredients, and by burning at a high heat, the quality of the product was vastly improved. The greater value of the Portland cement, producing as it does a mortar possessing about four times the strength at much less than twice the cost of the light, quick-setting artificial cements, gradually drove these from the market, and their manufacture soon ceased and has never been resumed.

It is not to be expected that the use of the natural light cements will be altogether superseded by that of Portland. For certain purposes they are as necessary, not to say as indispensible, at the present day, as they were when their introduction revolutionized the former methods of executing sub-marine constructions in masonry, by taking the place of the feebly hydraulic mixtures made from hydraulic lime, trass or natural or artificial puzzuolana. They possess sufficient strength for the purposes to which they are usually applied, viz., for massive concrete foundations and walls, for the concrete hearthing and backing of thick walls faced with ashlar or rubble, and for conferring hydraulic energy upon mortar for stone and brick masonry. At the same time it must be admitted that for similar purposes, good Portland cement, suitably diluted with common lime, in order to bring it down to the standard of the natural cements, is, in most localities, the least costly of the two.

For concrete work laid green under water, these quick cements are almost invariably to be preferred in the hands of ordinary workmen, for the obvious reasons that most of them not only hold the sand together, while in the plastic state, more tenaciously than Portland cement, but their prompt induration arrests the washing effects of the water, and tends to prevent the progressive separation of the sand and cement, before it has had time to proceed far enough to produce serious injury to the concrete.

Selenitic lime, or cement, patented by General Scott, of England, is prepared by mixing and grinding together unslaked eminently-hydraulic lime of the argillaceous type, and calcined gypsum, in the proportion of 93 to 95 per cent. of the lime, and 5 to 7 per cent. of the gypsum. When such a mixture is tempered to a paste with water, the slaking of the lime is prevented by the presence of the gypsum paste, and when made into mortar with the proper quantity of sand, it sets rapidly and well, and can be used for concrete, or mason's work, with a very considerable gain of strength. In Great Britain, the limes that have been found to answer the best for this purpose are the Burham, the Blue Lias, and the Barrow Lias, and none of them require the addition of more than 7 per cent. of calcined gypsum, to arrest their slaking in the presence of water and render them selenitic. In preparing the selenitic mortar, the proportion of gypsum for a given quantity of the lime is first mixed to a creamy paste in a portion of the water necessary to be used for the batch. After this the rest of the water is stirred in, then the lime is stirred in, and lastly, the sand is added and thoroughly incorporated. The mortar is then ready for use. No more mortar should be gauged than can be used the same day.

No suitable limes for selenitic mortar have yet been discovered in the United States. Several specimens that were hard, dense and strong, of selenitic mortar, plastering, and concrete, were exhibited by the Patent Selenitic Cement Company, of London, but their age and composition were not known. Some selenitic mortar was made under the direction of the agent of the company, with Howe's Cave hydraulic lime, rendered selenitic by the addition of five per cent. of gypsum. Equal parts of lime and sand were employed to render the results readily comparable with those obtained with the Portland and Roman cements. The specimens were not put into water after being moulded, and were tested when seven days old. The results are recorded in the accompanying table. Although the selenitic process confers great additional strength upon the Howe's Cave lime, it still falls far short of the English selenitic mortars, in consequence, it is claimed, of the unfitness of the lime for this process.

All the cements exhibited at Philadelphia were carefully tested before awards were recommended, by mixing them dry in each case with an equal measure of clean sand, tempering the mixture with water to the consistency of stiff masons mortar, and then moulding it into briquettes of suitable form for obtaining the tensile strength on a sectional area 1½ inches square, equal to 2¼ square inches. The briquettes were left in the air one day to set, then immersed in water for six days, and tested when seven days old. After thus obtaining the tensile strength in each case, the ends of the broken specimens were ground down to 1½ inch cubes, which were used the same day for obtaining the compressive strength by crushing. The results, averaged from a number of trials with each sample of cement, and divided by 2¼ in order to get the strength per square inch, are recorded in the following table. It may be stated in further explanation, that although the table shows, beyond question under the conditions named, the strength of the several mortars at the age of seven days, and hence the relative value for building purposes of the several specimens of cement exhibited, it may not correctly indicate the relative merits of the customary productions of the several manufactories represented. Some of them may have used especial care in preparing the article exhibited, while others may have sent average samples from stock on hand.

The quality of the well-known English Portland cement is fairly represented in the table, while that of Lonquéty & Co., of Boulogne, France, is not, for they have heretofore sold in the American market by the cargo, a better article than they sent to the exhibition. The Scanian cement from Sweden was badly used, having been exposed for three months in a loose pile on the floor, before specimens of it were furnished for testing. Its strength was doubtless considerably impaired thereby, and the results obtained with it were lower than those previously reported by a Swedish engineer.

The Parian cements are not hydraulic, and are used only for interior work. They were mixed with an equal measure of sand, and tested when seven days old, but the specimens were not kept in water. They were allowed to harden in the air, in one of the casemates of Fort Tompkins, Staten Island, New York.

CRUSHING AND TENSILE STRENGTH OF THE HYDRAULIC AND OTHER CEMENTS AT THE PHILADELPHIA EXHIBITION, TESTED IN THE MANNER EXPLAINED IN THE FOREGOING NOTES.

	Name of Exhibitor and Place of Manufacture.	Crushing Strength.		Tensile Strength.	
		Average Strength per Sq. Inch.	No. of Trials.	Average Strength per Sq. Inch.	No. of Trials.
	PORTLAND CEMENTS.	Pounds.		Pounds.	
1	Toepffer, Grawitz & Co., Stettin, Germany	1,439	12	216	3
2	Hollick & Co., London, England	1,330	10	216	3
3	Wouldham Cement Co., London, England	1,140	12	199	3
4	Saylor's Portland Cement, by Coplay Cement Company, Coplay, near Allentown, Pa., United States	1,078	8	184	2
5	Wampum Cement & Lime Co., Newcastle, Lawrence Co., Pa., United States	968	12	168	3
6	Pavin de Lafarge, Teil, canton of Viviers, department of Ardeche, France	931	12	158	3
7	A. H. Lavers, London, England	926	6	192	2
8	Francis & Co., London, England	907	14	163	3
9	Wm. McKay, Ottawa, Canada	882	10	141	3
10	Borst & Roggenkamp, Delfzyl, Netherlands	826	12	132	3
11	Lonquéty & Co., Boulogne-sur-mer, France	764	12	108	3
12	Riga Cement Co., by C. X. Schmidt, Riga, Russia	693	5	134	2
13	Scanian Cement Co., Lomma, near Malmö, Sweden	606	14	112	3
14	Brunö Hofmark, Port-Kund, Esthland, Russia	580	6	154	2
	ROMAN AND OTHER CEMENTS.				
15	Coplay Hydraulic Cement, by Coplay Cement Co., Coplay, near Allentown, Pa., United States	292	8	38	2
16	Charles Tremain, Manlius, N. Y., United States	276	12	47	3
17	Allen Cement Co., Siegfried's Bridge, Pa., United States	276	12	43	3
18	P. Gauvreau, Quebec, Canada	234	8	47	2
19	Riga Cement Co., by C. X. Schmidt, Riga, Russia	230	6	44	2
20	Anchor Cement, by Coplay Cement Co., Coplay, near Allentown, Pa., United States	208	12	41	3
21	Cumberland Hydraulic Cement Co., Cumberland, Md., United States	196	12	41	3
22	Societé Anonyme des chaux eminemment hydrauliques de l'Homme d'armes, pres Montélimar, France	184	7	29	2
23	Howe's Cave Associ'n, Howe's Cave, N.Y., U.S., No. 1	183	6	28	2
24	" " " " " No 2	170	10	43	2
25	" " " " " No. 3	170	8	31	2
26	Società Anonima per la fabbricazzione del cemente provincia di Reggio, Emilia, Italy ....1st quality	181	12	27	3
27	" " " " " 2d quality	154	12	22	3
28	Thomas Gowdy, of Limehouse, Ontario, Canada	126	8	23	2
29	A. H. Lavers, London, England	122	6	24	2
	SCOTT'S SELENITIC CEMENT.				
30	Patent Selenitic Cement Co., London, England (made with Howe's Cave lime and plaster)	298	20	52	5
	PARIAN CEMENTS.				
31	Francis & Co., London, England, 1st quality	1,175	8	181	3
32	" " " 2d quality	696	12	169	3
33	A. H. Lavers, London, England	205	6	51	2

IMPROVED CAST IRON.—Mr. J. G. Willans, of St. Stephen's Crescent, Bayswater, has patented a method of manufacturing a cast iron, containing a little silicon or phosphorus by melting down pigs in contact with carbon in a cupola furnace. Malleable castings and steel he makes from the cast iron.

THE USE OF THE MAGNETIC NEEDLE IN SEARCHING FOR MAGNETIC IRON ORE.

By Prof. J. C. SMOCK, of the State Geological Survey of New Jersey.

Transactions of American Institute of Mining Engineers.

The magnetic and polaric properties of magnetite, or magnetic iron ore, are fundamental facts in magnetism. The disturbing effect of this mineral upon the magnetic needle in land surveying must have been very early observed. The difficulties arising from this source are still almost insurmountable in making accurate surveys in districts where this ore occurs to any extent, either as a rock constituent, or in well-defined ore masses. In the Highland range from the Hudson to the Delaware Rivers, the ordinary method of running lines with the compass, is sometimes impossible, and property boundaries are located by well-established landmarks, rather than by the course of the needle. Notwithstanding these well-known facts, the general application of this property of deflection in the needle, by the presence of magnetite, to searches for this mineral, is comparatively of recent date. There are, however, authenticated instances of this use of the magnetic needle more than a century ago. The mining of iron ore in the Highlands began in the early part of the eighteenth century, and the Sterling, Ringwood, Dickerson, Andover, and Oxford Furnace Mines were all worked before the American Revolution. And these, with other old mines of this district, must have been opened shortly after the location of the larger patents and tracts of land, and the settlement of the country. And some of these ore masses were, most probably, discovered through disturbances observed in the action of the needle in making land surveys. This may have suggested the employment of the compass in searches for ore. Such use of the needle was made by the celebrated London Company, that took up the Ringwood tract. This company surveyed the country with thoroughness and success. And nearly all of the older and larger mines in this Highland belt are commonly reported to have been discovered through the use of the compass, in searches for ore.

The more general use of the magnetic needle for this purpose does not go back more than thirty years. In 1854, when the Geological Survey of New Jersey, under the direction of Dr. William Kitchell, began, the ordinary surveyor's compass was used by a few persons who were sufficiently experienced, or skilled by observation, to properly interpret its indications. At that time the number of large mines was not much greater than at the beginning of the century. The introduction of the miner's or dip compass shortly afterward, made the use of the needle much more convenient and extended, and work with it was done with much greater rapidity and accuracy than formerly. Contemporary with its introduction, began the greater frequency of discoveries, and the opening of many new mines and ore localities, so that this might be taken as an era in iron mining in New Jersey. Dr. Kitchell estimated the amount of iron ore raised in that State, in 1855, at 100,000 tons. In 1864, this had been increased to 264,600 tons, and in 1868, to about 300,000 tons. But the increase in the number of mines, from 1868 to 1874, is most remarkable. In the first-named year there were 115 mines and mine-groups, whereas, in 1874, the number of mines and ore localities had increased to nearly 200 in number.

It may be safely stated that all of these were first made known by the use of the needle. Or, in other words, the average annual production of the State had been increased fully fifty per cent. by the addition of these new producing localities found by the compass. So much the iron men owe to this little guide, or *true* divining-rod. It should also be stated, that in many cases there are no surface indications of ore, other than those of the compass.

At the present time, nearly every mine superintendent, and many landowners, have their dip compasses, and, as opportunity offers, go out in search of new lines of attraction. A few persons follow this business as a specialty, and open mines and deal in mineral properties. They are known as "ore hunters," or "prospectors," or "mineral dealers." For several years preceding the panic of 1873, the increasing demand for ore stimulated the search for new supplies, and many lines of attraction were found, and nearly every farm in this long belt was covered by a mineral lease.

Magnetism of Minerals and Rocks.—Magnetite is not, however, the only mineral which may disturb the needle and exhibit the deflection from the plane of the magnetic meridian termed *attraction.* Nor is this phenomenon of deflection confined to rocks containing this mineral. A large number of minerals are capable of producing slight deflection when they are brought near the needle. Serpentine, amphibole, pyroxene, hematite, and franklinite are some of the more powerful of these in their effects upon the magnetic needle. Many rocks also show some magnetism, particularly the darker-colored and more dense, igneous and volcanic rocks. This applies to the rock in masses as well as in hand specimens. In nearly all cases the magnetic disturbance is increased by heating to fusion or by oxidation. Probably in all these cases the magnetism is closely related to the presence or formation of both ferrous and ferric oxides in the mineral or rock species. Many of these exhibit polarity as well as magnetism. The greater intensity of this disturbing force in rocks and ores near the surface may be thus explained by an oxidation process through the agency of atmospheric forces. For a full statement of this subject of magnetism of minerals see an article by H. Tasche in *Jahrbuch der Kaiserlich-Koniglichen Geologischen Reichsanstalt,* VIII. Jahrgang, 1857. These phenomena observed in other minerals are interesting, but not of so great practical importance, since the experiment made with delicate instruments rarely showed more than two degrees of deflection, and practically they may be neglected. Very accurate and detailed magnetic surveys will yet be needed to embrace these elements in their range of work, and these elements will have to be eliminated to get at the correct indications coming from magnetite alone. Several lines of attraction observed in New Jersey, as yet unexplained, may be owing to the presence of strata containing these minerals, but it is very doubtful..

In practice, the attraction is to be referred to the near presence of magnetic iron ore, although the converse is not always correct, since there is a great range in the magnetic intensity exerted by ores, and some are so slightly magnetic that the deflection is perceptible only when the experiments are made with extreme care. Thus it is possible to pass with a dip compass right over large veins of ore, and yet fail to discover any attraction. Slight attractions over large and well-known veins are common in New Jersey. But careful surveys will generally reveal the disturbing effect and indicate ore. On the other hand, strongly magnetic and polaric ores are also common. In some instances the attraction is felt powerfully through wide intervals of rock or dirt or air. Hence no conclusions can be safely drawn from the amount of deflection or the magnetic intensity. These differences in the ore render the work of observation in some localities extremely easy, while in others there is need of repeated work, and that done slowly and cautiously.

As a rule the surface ores are most thoroughly magnetic, and this fact makes the survey of unexplored ground more easy. This difference between surface and bottom ores can be seen at almost any mine in this region.

Geological Occurrence of Magnetite in New Jersey.—The magnetite, as is well known, in this highland range, occurs either as a constituent of the rock strata, or in lenticular masses, imbedded between strata of rocks or walls. These ore bodies, in nearly every instance, have their shoots or longer axes in northeast and southwest lines, descending or pitching to the northeast, and they dip toward the southeast, and generally at steep angles. They may, therefore, be considered as approximately lying in the magnetic meridian and in a position to be influenced by terrestrial magnetism. Such an ore body would, therefore, have one pole at the uplifted or southwest end, while the other would be depressed beneath the surface toward the northeast. And the former ought to attract the north or positive pole of the magnetic needle, giving what is termed positive attraction, while the other end would exhibit a negative attraction. Or we may look at the two sides of this flattened, cylindrical ore body, the northwest and southeast, as poles, in which cases the former would give a negative, the latter a positive attraction. And experiments everywhere show these to be the results, just as here predicted of them.

But these ore masses or veins do not all trend in the above stated general or prevalent direction. Sometimes their course is from east to west or approximately such, while in other instances the trend or strike is more nearly north and south.

In the east and west strike the two sides of the vein constitute the poles, and of course such lines are necessarily short, and the magnetism feeble. The more nearly the axis of the shoots of ore or vein corresponds to the magnetic axis, other things being equal, the stronger the magnetism and the more clearly the line and character of the attraction.

From these general statements it will be evident that positive attraction will be most commonly observed, the northeast end being too deeply buried to exert any measurable effect upon the compass at the surface, and as a rule the attraction diminishes toward the northeast until it is gradually lost. But from the geological structure of this region it is well known that these veins are very frequently broken by faults or consist of separate shoots, lying in a general northeast and southwest direction. In each of these cases there are a series of ore masses, and the opposite ends of these must show opposite kinds of attraction.

Hence, where there is a fault, and at the interval between two distinct shoots, both positive and negative attraction will be observed within short distances. On the south side it will be negative, on the north positive. Hence, a change from positive to negative entirely across the vein indicates a fault. Such transitions are common, and when met with the projector understands it to be a fault, or off-set. It is possible, therefore, *a priori*, to predicate the character of the attraction, if we have given the mode of occurrence of the ore. And from these the converse reasoning is safe, and practice, repeated in hundreds of cases in mining in New Jersey, has proved the correctness of these deductions.

Styles of Compass.—Formerly the ordinary pocket box-compass, in which the needle is horizontal, was used in searching for attraction, the observer holding it in his hand and noting from point to point the amount of deflection from the magnetic meridian. Sometimes, and where a more careful survey was required, the land surveyor's compass was used, and then lines were run back and forth, across the course of the vein, sighting ahead and noting from point to point in these lines the bearing of the object toward which the line was directed. When these lines were properly located, and the points of observation fixed, and the several observations on them recorded, good work was done. But it was necessarily slow, as each observation required some time, particularly if the attraction was slight.

About ten years ago the miner's, or dip-compass was introduced. This has its needle balanced on a horizontal axis, and free to move in a vertical plane only. In the most common form this is from two to four inches in length and is shut in a flat, circular brass box with glass sides, in some cases open, in more improved forms protected by movable brass plates or covers, which are taken off while in use. This style of compass has superseded the horizontal surveyor's instrument, and has come into very general use. It is often called the dipping-needle or dip-compass.

As in this form the needle cannot move horizontally, care must always be taken to ascertain the magnetic meridian, and to hold the instrument in the plane of that meridian, otherwise the needle, under the influence of terrestrial magnetism alone, will assume an inclined or vertical position, and thus show a dip, or attraction, where, in reality, there is none. Neglect of this precaution has misled many an observer, and intentional disregard of it has very frequently deceived the ignorant or unsuspecting. The extent to which deception in this manner has been practiced is hardly conceivable by those unacquainted with the magnetic iron ore districts of the Highlands.

In Sweden, a miner's compass, having its needle mounted upon a pivotal joint, which allows of motion, both vertically and horizontally, and inclosed in a glass sphere, or cylindrical brass case, has been used in ore searches. But there is objection to this form in the unsteadiness of the needle, which has so much play that more time is requisite in making observations with it.

A newer form, designed by Prof. Cook, of the State Geological Survey of New Jersey, about five years ago, and constructed by W. & L. E. Gurley, of Troy, removes the objection in the Swedish compass, by allowing the needle, which is balanced on its horizontal axis, to move horizontally through a small fraction of a great circle. This, therefore, shows the magnetic meridian much more quickly than the Swedish instrument; and then, if there be any attraction, it is manifested in the dip, avoiding any possible danger of deception, through the action of the earth's magnetism upon a needle not placed in the magnetic meridian. This most improved compass has its movable brass sides for safety in carrying, and the ordinary ring set in the brass edge, whereby to hold it. The graduated circle is the same as in the old form. Those who have had much experience in magnetic surveys, give the preference to this compass, as the most accurate, convenient, and most efficient, either for rapid preliminary observations, or for detailed exploration.

In use, the compass is generally held about on a level with the eye of the observer, or so that he can conveniently watch the movement of the needle, and read off the graduated circles the amount of dip. After some experience great dexterity is acquired, and from the vibrations, the experienced eye can readily detect what will probably be the character and the amount of the dip, or attraction. Such an observer may move along on a slow walk and observe, or, as it is technically termed, *catch* the attraction, if there be any in the course he may follow.

Surveys.—In a preliminary survey of any given tract, the usual practice is to go rather rapidly on zigzag lines, from northwest to southeast; or, if attraction be known, or found at any given point, to walk northeastward and southwestward from that point, following on the supposed, or assumed course of the ore, and thus ascertaining its longitudinal extent. This gives the general direction and length of the line, or belt of attraction. This preliminary survey does not generally require more than a single line of observations, and these are not located or recorded, excepting so far as the observer may refer them, in his memory, to any landmarks that may be prominent or convenient for further observations.

Detailed surveys, or what may be properly termed "magnetic surveys," may be more or less varied, according as the nature of the attraction may seem to require a greater or less number of observations within a given area.

In general, the most convenient and most expeditious method, and, at the same time, that which is best suited to show the character of the attraction or observations, consists in taking observations on lines at right angles to the course of the vein, or across the belt or line of attraction. Where the prevailing course, or strike, is northeast and southwest, as in the Highlands, these should be northwest and southeast lines. Of course, they may be at greater or less distances apart, according as the nature of the attraction may indicate, or the degree of detail demanded in the survey. In general, they may be from 50 to 200 feet apart, or in exceptional cases as close as 20 feet. The stations, or points of observation in these lines, may likewise be at varying distances, from five to twenty-five feet apart. Ten feet has been found to be convenient, and sufficiently close for careful and valuable surveys. Such detailed observations, to be of value, must be located and recorded; or, in other words, mapped. For this purpose it is easier to run parallel lines, or such as are approximately so, and make the observations at regular intervals.

Stakes may be driven at the ends of these, and a subsequent survey may be made to locate them. The observed dips, or the amount of attraction, can then be placed at fixed intervals on these lines. Such a method is much more expeditious than a far more detailed survey at *irregular* points. While a great deal of work has been done by the numerous prospectors in this iron ore district, and large areas have been covered by a network of closely placed observations, very little work has been recorded on maps.

Geological Survey of New Jersey.—The geological survey of New Jersey has traced out some lines of attraction, and placed them upon record—upon geological maps—but these do not show the character or the amount of attraction. The scale of these maps is too small for the exhibition of these facts. Three sketch-maps, but of limited areas, giving the observations and their location, appeared in the "Annual Report for the year 1873." These were on a scale of eighty feet to an inch. In these the dots represent the stations, and the figures the observed amount of attraction, the minus sign indicating a negative attraction, and the figures alone positive attraction.

During the past summer the Green Pond Iron Mining Company had a magnetic survey made of its large tract of 600 acres of mineral land, in Morris County, about fifteen miles south of Dover, N. J. This was crossed in a preliminary survey by lines 200 feet apart, running northwest and southeast, and then the areas, where over 5° of attraction were observed, were covered by lines fifty feet apart, with observations at intervals of fifteen feet. This map shows three separate lines or belts of attraction which trend north 54° east (referred to true meridian). The openings on one of these lines have been such as to expose a large *vein* of ore, or rather a long line of *shoots* of ore.

Deductions from Indications.—Having made such a survey, we are very naturally asked what inferences follow certain indications or what are such surveys worth? The diversity in the character of lines of attraction may be very great, almost as varied as the possible arrangement of the stations, but certain general characters are recognized as indicative of corresponding occurrences of ore beneath, and all the varied phenomena may be classified in a few groups, described by a few generalizations.

The line of attraction may be long and steady or regular, that is, there may be a line of maxima dips, from which, toward either side, these diminish and at length disappear; and these maxima may correspond more or less closely in amount as well as in location. Such a line indicates regularity below, either in the form of an ore vein or a series of stratified ore-bearing rocks, of nearly homogeneous character throughout. Conversely, if in the line the attraction be irregular in amount, very strong in close juxtaposition with slight or weak attraction, or if the maxima in the several parallel lines which cross the vein, are not in line, but varying from side to side or in amount, on one slight, on the next strong, etc., such indications show irregularity in the occurrence of the ore.

Generally such very irregular attraction is found wherever magnetite occurs as an inconstant and accessory mineral constituent of unstratified, granitic, or syenitic rock masses. Inasmuch as the attraction in such places is apt to be very strong, frequently holding the needle vertically, it is likely to mislead the ore hunter, and many instances of fruitless work in digging and shafting for ore on such attractions have been observed in New Jersey. Popularly a few strong observations far outweigh the longer lines of constant but slight dips. But there is a variation in the character as well as in the amount of the dip, that is, the dip or attraction is sometimes positive and sometimes negative. And here, too, the transitions from the one to the other may be very sudden, and frequently recurring with limited areas.

From what was stated at the outset, positive attractions would be anticipated as the predominant character, prevailing along the whole line, excepting on the northwest side, and in those cases where the ore may not be continuous, either on account of faulting or in consequence of its occurrence in separate shoots, lying *en échelon* in the general course of the vein. In these a negative attraction would be anticipated, and this is found to be the case. And hence such transitions from positive to negative are indications of breaks in the ore mass, faults or separate ore-shoots. Repeated observations over faults prove this.

Conclusions.—This method of examining ground for magnetic iron ore is so well understood and so extensively practiced in New Jersey, that such a description is hardly more than a statement of facts there gathered.

In the further extension of such surveys, greater care is requisite both in the manner of taking observations and in recording them upon carefully constructed maps. Hereafter more attention must be paid to the slighter attractions and to the regular work of accurately mapping them. Such care is necessary, not only to discover new lines, but also to so ascertain the character of known ones as to enable the miner to locate properly his trial pits and shafts. And it appears proper to put this before the attention of mining engineers and geologists, wherever there are magnetite iron ores, since careful preliminary works with the magnetic needle may in other States as well as in New Jersey, largely increase the number of localities whence our supplies of ore may be drawn.

ON THE WORKING OF STEEP GRADIENTS AND SHARP CURVES ON RAILWAYS.

By Capt. HENRY WHATLEY TYLER, Assoc. Inst. C. E.

Proceedings of the Institution of Civil Engineers.

The comparative terms, steep and sharp, have acquired at the present day a signification very different from what they conveyed to Engineers a few years since. The locomotive engine has been gradually trained and adapted to gradients of 1 in 100, 1 in 50, 1 in 25, and 1 in 12, combined with curves of from 30 chains down to 15, 10, 5, and even 2 chains radius; and during all this progress, the result of so much labor and ingenuity, the system of bite, or adhesion, by plain surfaces, has steadily triumphed as a means of converting steam-power into tractive force. The well-known rack-rail of Blenkinsop, as well as the Archimedian screw of Grassi, and the grooved wheels of other inventors, have all succumbed before it. The coefficient of adhesion was always in the first instance under-estimated. Legs or feet were most cleverly contrived to enable engines to walk, so to speak, before they could run; and the central rail system of Vignoles and Ericsson, patented so far back as 1830, was intended to provide extra adhesion on what are now considered moderate gradients, in place, apparently, of the rack-rail. The defects of the rack-rail appear to have been,—the risk of fracturing the teeth; the liability of the teeth to be choked with dirt, snow, or ice; the slip which resulted as the teeth began to wear, and the continued blows which they occasioned to the locomotive, causing it to be, in fact, always "on the rack." Grooved wheels afford obviously increased bite; but there must be, when they are used for locomotive purposes, continual abrasion from unequal travel of the surfaces in contact, with increased friction on curves, and some loss of power, in proportion to the increased bite obtained, from what may be termed back-adhesion. The screw of Signor Grassi—to work under his engine on a series of rollers along the permanent way—was reported upon by Captain Moorsom, in 1857. Captain Moorsom expected a load of 80 tons to be taken by its means, in place of 50 tons by "an ordinary bank-engine," up 1 in 20; but he stated that there would be three peculiar difficulties to contend with:—(1) The maintenance of exact action between the wheel and the screw. (2) The friction of the rollers. (3) Economy of maintenance of engine and road. The screw was to be 13 inches in diameter, winding round a shaft 7 inches in diameter, with a pitch of 12½ inches, and 5 feet 4 inches long, grasping two rollers at a time on the permanent way. These rollers, 8½ inches in diameter, were to be placed 3 feet 2 inches apart from center to center. A bevelled wheel on the driving-axle of the engine was to be connected with a crown wheel on the end of the screw shaft, and the proportions were to be such, that each revolution of the driving-wheel was to turn the screw twelve times. This system was ingenious, but wanted many of the advantages which will be hereafter referred to as arising out of the use of the central rail.

In this country the Lickey incline of 1

in 37, the incline of 1 in 30 on the Folkestone Harbor branch, the Oldham incline of 1 in 27, and the navigation incline of the Taff Vale Railway of 1 in 18, have, with others, been worked for a greater or less number of years with what may be called engines of ordinary construction. And it was stated in this Institution, in 1858, that an eight-wheel coupled engine, weighing 24 tons, was in the habit of taking its tender and a carload of iron, together weighing 25 tons, over a gradient steeper than 1 in 10, at a speed of from 8 to 10 miles an hour. This required, however, as will be observed, an adhesion of between one-fourth and one-fifth of the weight of the engine, which is more than could be relied upon, at all events in this climate. But in conveying heavy loads up gradients much less steep than those referred to, a want of extra adhesion has been seriously felt, and various expedients have been resorted to for obtaining it. The most comprehensive proposal with this view was that of M. Flachat, who, in a paper laid before the Society of Engineers in Paris, in 1859, desired, in constructing railways over the Alps, to utilize the adhesion, not only of all the wheels of the engine and tender, but also, by the use of additional cylinders, &c., to them, of all the vehicles composing a train. M. Flachat says, "La puissance motrice, au lieu d'être concentrée sur six roues, s'appliquerait ici à 32 ou 40 roues; elle sera donc dans des conditions d'utilisation bien supérieures. Ce qui manquera aux unes, par une diminution éventuelle d'adhérence, sera reporté sur les autres, de telle sorte que cette puissance ne pourra s'annuler à la fois entièrement pour tout un train, comme cela a lieu par le patinage de la machine." Mr. Sturrock has acted in this country, *sed longo intervallo*, in the same direction, having contented himsef with adding cylinders and the necessary apparatus to his tenders, which he has now for some time employed as assistant engines on certain parts of the Great Northern Railway. The engine and steam-tender together weigh, when fully loaded, between 60 and 70 tons.

M. Thouvenot, on the Continent, and Mr. Fairlie—who has published a most interesting pamphlet on the subject—in this country, employ two tank-engines in one, placed, as it were, back to back, and united as to their boilers and fire-boxes. They thus obtain double engines, which are intended to be worked by two men only, which have double power, intended to run either end foremost, and which are adapted for sharp curves. There being four cylinders, the wheels under each engine are coupled together, independently of those under the other engine. M. Thouvenot's engine weighs upwards of 80 tons, while Mr. Fairlie estimates his heavy goods engine at 60 tons, and states that it would draw (including its own weight) 170 tons, up a gradient of 1 in 12, at 10 miles an hour. But this is allowing between one-third and one-fourth for adhesion; whereas if one-ninth were allowed for adhesion, the same engine would only be able to take 72 tons altogether, or 12 tons besides its own weight, up the same gradient.

In the ordinary system of obtaining adhesion by bearing-wheels only, whether of an engine and tender, or of a double engine, or of two engines coupled together, the weight of the motive power requires to be increased for a given amount of adhesion, in proportion to the load or to the steepness of the gradient. The limit of the gradient up which such an engine can take a load may roughly be defined by the coefficient allowed for adhesion; and it is necessary, of course, in practice, particularly on very steep gradients, to allow for, not an average, but nearly the lowest, rather than the best adhesion that can be obtained. If, for instance, one-tenth be allowed, then 1 in 10 is (omitting friction) the gradient on which an engine may move itself, but on which no load can be taken. If one-twelfth be allowed, then 1 in 12 is the gradient of no load; and so, in all climates where from one-tenth to one-twelfth only of adhesion can be relied on, no amount of increase in weight, or arrangement of the parts of an engine, will admit of trains being worked on such gradients. Mr. Fell, therefore, when brought face to face with the Mont Cenis, on which the adhesion may vary from one-sixth to one-twelfth, and on which gradients were required of 1 in 12, was obliged to adopt some other method than that of trusting to adhesion by bearing-wheels; and having a high summit to surmount, it was of great importance to him, with reference to cost of working, to save weight in the engine as well as in the train. By wisely adopting the principle of horizontal wheels and a central rail, he found the means of doubling the adhesion, at the same time that by the use of steel, he made the engine lighter than it would otherwise have been.

The central rail system was first patented, as already stated, for extra adhesion, by Mr. Vignoles, and Mr. Ericsson, on the 7th September, 1830; and next on the 15th October, 1840, by Mr. H. Pinkus, in England. It was proposed by the Baron Séguier, in December 1843, to "L'Académie des Sciences," as a means of safety for general application, and patented by him three years later. It was again patented in England by Mr. Seller, under the name of A. V. Newton, on the 13th July, 1847; and lastly by Mr. Fell, who has, with the assistance and influence of Mr. Brassey, been the first to carry it into practice, in January and December, 1863.

It has been tried with two engines, and upon two experimental lines. The first experimental line, 800 yards long, containing 180 yards of straight line, on a gradient of 1 in 13.5, and 150 yards of curves, with radii of 2½ and 3½ chains, was on the Cromford and High Peak Railway, in Derbyshire. The second, a mile and a quarter long, on an average gradient of 1 in 13, containing, besides others, 480 yards of curves with radii varying from 4 to 2 chains, and terminating at an elevation of 5,815 English feet above the sea, was laid on the road over the Mont Cenis.

These lines were laid on a guage of 1.10 mèter or (3 feet 7⅝ inches) with bearing rails of the ordinary description, but with a third rail laid on its side horizontally and centrally between them at an elevation (to its center) of 7½ inches above them. On the Mont Cenis, the central and bearing rails were borrowed from the Victor Emmanuel Railway Company, and weighed about 75 lbs. to the lineal yard. The chairs which supported the middle rail were partly of wrought and partly of cast iron; they weighed 20 lbs. each at the joints, and 16 lbs. each in the intermediate spaces: they were placed six feet apart on the straight line, and from 2 to 3 feet apart on the curves; and they rested on longitudinal timbers, 8 inches deep by 12 inches wide, which were spiked to the transverse sleepers.

The first engine weighed 16 tons when loaded with coke and water. It has a heating surface of 420 square feet, and a grate area of 6 feet 6 inches. It is provided with four cylinders, two outside cylinders 11¾ inches in diameter, with a stroke of 18 inches, for working four coupled vertical wheels 2 feet 3 inches in diameter, with a wheel-base of 5 feet 3 inches; and two inside cylinders 11 inches in diameter, with a stroke of 10 inches, for working four horizontal coupled wheels 1 foot 4 inches in diameter, with a wheel-base of 1 foot 7 inches. It has a pressure of 16 tons on the horizontal wheels, or about the same weight as is carried by the vertical wheels. Guide-wheels have also been added to the trailing end, to act upon the middle rail.

The machinery of this engine is too much crowded together for convenience in re-adjustment or repair; its boiler power is not sufficient for working the traffic of the Mont Cenis; and the oil from its machinery falls upon the horizontal wheels, and deprives them, to some extent, of their power of adhesion; but it has answered its purpose in proving the principle which it was constructed to test, and has been, considering its novelty, a surprising success.

The second engine, constructed specially for the Mont Cenis, is partly of steel. Its net weight is now 14 tons, and its mean weight, when fully loaded with fuel and water, 17 tons, of which 2 tons 13 cwt. is for the machinery connected with the horizontal wheels. The boiler is 8 feet 4½ inches long, and 3 feet 2 inches in diameter, and contains one hundred and fifty-eight tubes of 1½ inch external diameter. The fire-box and tubes contain altogether 600 superficial feet of heating surface, and there are 10 feet of fire-grate area. There are only two cylinders, with a diameter of 15 inches and stroke of 16 inches, which work both the four coupled horizontal, and the four coupled vertical wheels, which are all 27 inches in diameter. The wheel base of the vertical wheels is 6 feet 10 inches, and that of the horizontal wheels is 2 feet 4 inches. The maximum pressure in the boiler is 120 lbs. This engine, without guide-wheels before or behind, travels with its longer (horizontal) wheel-base more steadily than No. 1; its machinery is more easily attended to, and the pressure upon its horizontal wheels can be regulated by the engine-driver at pleasure from the foot-plate. This pressure is applied through an iron shaft connected by means of right and left handed screws with a beam on each side of the middle rail, and these beams act upon volute springs which press the horizontal wheels against that rail. The pressure employed during the experiments was from 2½ to 3 tons on each horizontal wheel, or 10 tons altogether; but the pressure actually provided for, and which may, when necessary, be employed, is 6 tons upon each, or 24 tons upon the four horizontal wheels. The vertical wheels are worked indirectly by piston-rods from the front, and the horizontal wheels directly by piston-rods from the back of the cylinders.

The Author himself observed, that No. 2 Engine was just able to move up a gradient of 1 in 12½ with 40 lbs. of steam-pressure. This engine developed 12 horse-power per ton of its own weight; but it is believed that by some alterations in the boiler, as well as in other parts of the engine, in which steel may be substituted for cast iron, something like 15 horse-power per ton may ultimately be obtained, as against 20 horse-power per ton which is afforded by steam fire-engines.

It was remarked during the later trials, that the engine and train gained speed on the sharpest curves. This effect, so contrary to general practice, was produced, partly by the action of the horizontal guide-wheels, which kept the engine and the wagons in their proper positions with respect to the rails, and partly to the fact that the gradients on the curves had been slightly eased, while the gradients on the straighter portions had been made proportionally steeper, with the intention of as nearly as possible balancing the resistances. There is the less practical difficulty in carrying out this advantageous arrangement upon very sharp curves, because such cannot of course be of great length.

The advantages of this system for mountain passes are very great. The middle rail, besides being of service in the ascent, affords the means of applying pressure-breaks, acting with any amount of force, to any number of vehicles in the descent, and thus renders the descent safe, and supplies a remedy against bad consequences from a fracture of the couplings. It also prevents the engine, or any vehicles of the train that are supplied with guide-wheels, from leaving the line, from a defect in the permanent way or rolling stock. The force of the wind is at times so great on the Mont Cenis that it would hardly be safe, if only on that account, to take trains over it without the protection thus afforded.

There is another system for working steep inclines which has found support in Italy, and which it will be proper to describe here—that of Signor Agudio. In this system two stationary engines are employed, one at the summit and the other at the bottom of an incline plane. They have the same power, and they act upon the same double endless rope, which is kept stretched by a tension wagon hanging upon it at each extremity. This rope runs between the rails, and over two systems of wheels worked by the stationary engines, from which it receives its movement by friction. It does not act directly upon the train, but is connected with an engine which may be called the locomotive of the system, and has received from the inventor the name of "Locomoteur funiculaire." This is a vehicle 22 feet long, supported on a bogie-frame at each end, and carrying a system of drums and wheels, by the action of which the required motive power is obtained indirectly from the moving rope. The two portions of rope act upon separate wheels, the wheels set the drums in motion, and the drums climb a heavy stationary iron cable, firmly fixed at the summit and weighted below, which is called the "cable of adhesion." The ascending portion of the moving rope has two turns round two wheels on the left side, and the descending portion two turns round two wheels on the right side of the locomotive, the front wheels in each case remaining free, and being used for conducting the rope only, while the hind wheels transmit to the drum the moving power of the rope. The ascending rope acts through its (left) hind wheel upon a middle friction drum, which is compressed between the outer main drums by the force of the rope passing over them, and which thus turns the main drums on each side of it by adhesion. The descending rope acts through its (right) hind wheel upon a pinion and a rack in the inner circumference of the hinder drum. The drums being set in motion, the locomotive is moved by their friction upon the cable of adhesion which has two turns round them.

The middle drum which transmits the force of the ascending portion of the rope to the main drums, and the rack and pinion which transmit the force of the descending portion to the hinder drum, are so proportioned that the rope moves at two and a quarter times the speed of the locomotive; and as the two portions of the rope work equally, the strain on the rope is, excluding friction in both cases, $\frac{1}{2.25}\times\frac{1}{2}=\frac{1}{4.5}$, or 2-ninths of what it would be in the case of a single rope acting by direct tension in the ordinary way. The moving rope of the system may therefore be proportionately diminished in strength and weight, or a greater length of inclined plane may be worked than under the ordinary system, with greater safety, though at the expense of a certain amount of complication.

The hinder rope-wheels of the locomotive are provided with gearing which will admit of their running free, or with their shafts, at pleasure. Before starting they are allowed to run free, and when a certain velocity has been attained, that which is connected with the friction drum is suddenly put into gear, and the excess of velocity is utilized in overcoming the inertia of the train and the apparatus. In ascending, the train may at any moment be stopped by putting these wheels out of gear and applying the break. There is a break attached to one of the drums and a sledge break on the rails, which may be used in the descent, when the moving ropes are stationary and the rope-wheels run freely on their shafts.

Some experiments which were tried with this system on the Dusino incline between Turin and Genoa appear to have given great satisfaction to the Commissioners of the Royal Institute of Lombardy. The incline was 2,400 mèters (1½ mile) long, on variable gradients of 1 in 26 to 1 in 31, and the sharpest curve had a radius of 350 mèters, or 17⅜ chains. The total passive resistance for a train of 120 tons on this incline was estimated at 44 per cent.; and it was calculated by the inventor that he would be able to save 605,245 francs out of 776,228 francs annually in the working of the Giovi incline. He proposed, however, to employ water-power for his stationary engines.

The useful effect of the system is calculated at 57.7 per cent. by the inventor as the result of the experiments on a length of 1½ mile; at 50 per cent. for a length of 5 kilomèters (3 miles) by the Italian Commissioners who reported on the Mont Cenis Railway; and at 47 per cent. by M. Desbrière for a length of 6 kilomèters (3¾ miles). M. Desbrière represents it perhaps rather too favorably in allowing no diminution of useful effect as the gradients become steeper. It is true that the friction of the parts would remain nearly the same, but the weight of the locomotive being constant, it would bear a greater proportion to the trains as the gradients became steeper, and to that extent diminish the useful effect.

It is a question, whether, in the practical application of the system, the toothed wheels through which the force of the descending portions of the rope is applied, should not be replaced by wheels acting by adhesion; and it is a still more important question whether, supposing the principle of the moving ropes to be applied, a middle rail ought not to be employed in the place of the "cable of adhesion," as has been, indeed, already proposed by the inventor. Horizontal pressure-wheels in the locomotive might be made to act with any required amount of pressure upon a middle rail, in place of the drums acting upon the cable of adhesion, and many important advantages would thus be obtained. 1. The weight of the locomotive might be reduced. 2. Much sharper curves might be employed. 3. A greater degree of safety would be attainable in the important items of (*a*) preventing, by the use of the horizontal wheels, all risk to the locomotive or any of the vehicles behind it from their leaving the rails, (*b*) affording a means of applying a break, by pressure upon the middle rail, which would admit of a train being stopped without difficulty upon any gradient.

A modified Agudio system—with the double-wire rope and a middle rail—worked by stationary engines, might probably in some cases be adopted with advantage for passenger traffic on gradients steeper than 1 in 10 or 1 in 12. The defects of the system—that it can only be worked for lengths of 4 to 5 miles, and that it does not admit of the use of very sharp curves—would be insignificant if gradients of 1 in 4 or 1 in 5 were employed in suitable localities. At high elevations, however, where the ropes would be liable to be covered with snow and ice, the system would be inapplicable, at all events excepting under complete cover; and steam-power would be required, inasmuch as water-power would not be available in seasons of low temperature.

It does not appear that this system, or any other yet developed, can compete with the central rail system for general traffic on very steep gradients up to 1 in 10 or 1 in 12; and the principal questions that remain to be considered are, the relative economy of summit lines with steeper gradients, and tunnel lines with less steep gradients, and the limit from which the central rail may be profitably employed. The best comparison that can at present be made in regard to the former point is between the Mont Cenis Railway and the Grand Alpine Tunnel.

The Italian Commissioners who reported on the experiments on the Mont Cenis, themselves admit a saving of 84,000,000fr. out of 123,000,000fr. in favor of an improved and permanent summit line, as compared with the tunnel line which the Italian Government constructed to connect Modane with Susa. They arrive at this result by deducting 16,600,000fr. as the cost of an improved summit line, and 22,400,000fr. at which they estimate the capitalized difference of working expenses (over a super-elevation of 2,500 feet) from the estimated amount, as above, of 123,000,000fr. for the tunnel line. But Mr. Fell points out that they have omitted 10,000,000fr. for the portion of their own line between Modane and St. Michel: they have inadvertently charged 1,000,000fr. for extra rolling stock for the summit line twice over; and they have overcharged the capitalized extra working expenses by 10,000,000fr. on the one hand, at the same time that they have omitted 800,000fr.—the cost of the extra portion of the tunnel line from Susa to Bussolino—on the other hand. The Italian estimate thus modified shows a saving in favor of the summit line of 104,800,000fr. out of 133,800,000fr., or, in other words, places the total cost of constructing and permanently working this particular summit line at less than one-fourth of the tunnel line.

The Italian Commissioners who reported to their Government upon the best mode of crossing the Swiss Alps, took considerable pains, also, to calculate the relative cost of conveying passengers and goods by tunnel lines or summit lines such as that over the Mont Cenis. Taking into account the total capital to be expended, and the cost of working in each case, they came to the conclusion that the cost of the tunnel line would be: for goods, 28 centimes per ton per kilomèter, and for passengers, 17 centimes each per kilomèter; as against on the summit line: for goods 10 centimes per ton per kilomèter, and for passengers, 6 centimes each per kilometer, showing that there would be a reduction of total cost amounting to about 64 per cent. in favor of the summit line, with a loss of time, for passengers, of thirty-eight minutes upon 48 miles against the summit line, in the passage of the Mont Cenis.

The particular gradients on which the central rail may properly be applied must, of course, vary with the coefficient of adhesion and other local circumstances, and be left in each case to the discretion of the Engineer.

Neglecting the questions of speed and steam-power, and assuming one-tenth as the coefficient of adhesion, then the proportions of net load that could be taken up the following gradients by two engines, each of 20 tons, one of ordinary construction, and the other with horizontal wheels and a supplementary adhesion of 1½, would be respectively:

For 1 in 20	20 tons net load for ordinary engine 80 " " central rail engine	or 1 to 4
For 1 in 16	12 " " ordinary engine 60 " " central rail engine	or 1 to 5
For 1 in 12	4 " " ordinary engine 40 " " central rail engine	or 1 to 10
Similarly for an adhesion of $\frac{1}{7}$:		
For 1 in 20	39 tons net load for ordinary engine 129 " " central rail engine	or 1 to $3\frac{1}{4}$
For 1 in 16	27 " " ordinary engine 99 " " central rail engine	or 1 to $3\frac{1}{2}$
For 1 in 12	15 " " ordinary engine 69 " " central rail engine	or 1 to $4\frac{1}{2}$

But these advantages would, of course, only be available as long as the adhesion was insufficient in an ordinary engine for the steam power, and would disappear in such a case as that which—though it can hardly be credited—was reported from the Alleghany Mountains in America, in the Paper already referred to, where, on a gradient steeper than 1 in 10, an ordinary engine (with an adhesion apparently of $\frac{1}{4}$) is stated to have worked with a load. The following Table, from the Paper of M. Desbrière, before alluded to, gives the result of his calculations.

Table of minimum weight to be allowed, with an adhesion of one tenth to

(1.) An ordinary locomotive engine with wheels all coupled.

(2.) A central-rail engine, with 1.5 of supplementary adhesion, to draw a net load of 100 tons on different gradients, compared with the weight which would result, for each system, with heating surface corresponding to various speeds:

Gradients.	Weight necessary for adhesion of Locomotive Engines.		Speed in Kilometer per Hour.	Total Force.		Weight required for Steam Power.	
	Ordinary.	Central Rail.		Ordinary Engine.	Central Rail Engine.	Ordinary Engine, System Pétiet, 120 kilos. per H.P.	Central Rail Engine, 112 kilos. H.P.
Millims.	kilos.	kilos.	kiloms.	H.P.	H.P.	kilos.	kilos.
0	5.000	2.000	72	146.66	146.66	16.352	16.352
10	16.440	6.250	30	203.33	190.00	24.400	21.280
20	31.250	10.860	20	254.80	217.77	30.576	24.390
30	50.000	15.900	15	305.50	243.33	36.660	27.252
40	75.000	21.430	12	366.60	257.30	43.992	28.617
50	110.000	27.500	10	448.10	280.00	53.772	31.360
60	162.500	34.730	10	659.40	346.86	78.128	38.852
70	250.000	41.660	10	1,014.75	422.50	121.680	47.320
80	425.000	50.000	10	1,725.00	482.80	207.000	54.073
90	950.000	59.440	..	..	..	..	..
100	..	70.000	..	..	..	..	..

Precise calculation is, however, of limited value, when the coefficient of adhesion, the principle element, is so very variable. But no English Engineer would probably contemplate working any considerable length of railway permanently on a steeper gradient than about 1 in 25 without the margin for adhesion afforded by, and the additional safety of, the central rail; and it might, no doubt, be frequently used with advantage on gradients less steep than 1 in 25. A country which requires very steep gradients demands also, in most cases, very sharp curves; and the central rail contributes to safety as much in respect to the latter as to the former. It also contributes in an important degree to economy, by diminution of friction in passing round very sharp curves, by which loss of power and wear and tear are equally avoided. And it may be added, in conclusion, as a result of experience, that the bearing-wheels of the engine left the bearing-rails once during construction, and once before the Italian Commission, on the Mont Cenis Experimental Railway, and were brought back to them on both occasions by the guiding power of the central rail.

SOME SPECIAL FEATURES IN LARGE AND SMALL GRAIN POWDERS.

By Major J. P. MORGAN, R.A.

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It is the third time that I have read a paper on the subject of gunpowder. The first was on the determination of its explosive force, without an accurate knowledge of which no scientific progress can be made in its manufacture. The second showed the difficulties which had been encountered, and the success which had been achieved in the manufacture of pebble powder. In the present paper, assuming the conditions on which the thorough ignition of a charge mainly depends, I intend to show how great an approximation there is to these conditions in the special features which regulate the burning of the individual grains of powder themselves, and how this depends not only on the size of the grains, but also on the facility with which the flame can penetrate towards the centre of the grain, and on the rate of burning of the particles of charcoal of which it is partly composed.

It is not many years since two sorts of powder only were sufficient for nearly every requirement of the Service, viz., Large Grain or L.G., for guns, and Fine Grain or F.G., for small arms. Both of these powders were manufactured in the same manner from the same description of charcoal, viz., alder or willow, differing from each other only in the sizes of the grain, L.G. being sifted between meshes of 8 and 16 to the inch, and F.G. between those of 16 and 36.

On the introduction of rifled small arms, F.G. was found unsuitable, and the first and most important alteration was the substitution of dogwood for alder, or willow charcoal. This necessitated the entire separation of the manufacture of small arm powder from that of powder for guns. The first powder of this description was made in 1859, and was of a size 16 to 24-mesh. It was known as Enfield Rifle, or E.R. powder. In 1860, the size of grain was increased to a 12 to 20-mesh, and the powder was called J. 2 until 1875, when the name was changed to Rifle Fine Grain or R.F.G. These dogwood powders can be distinguished from the old F.G., not only by the size of the grain, but more readily by the charcoal being browner and the grain being rounder and not so flakey. The inner portion of dogwood is of a reddish brown color, and this color is imparted to the charcoal and thus to the powder. The roundness of the grain is due to the soft friable nature of the charcoal, dogwood being a small soft wood and easily charred.

It has always been found that powders made from dogwood are more violent than those made from alder or willow. Some have thought that this is due to the larger proportion of gaseous matter in the constitution of dogwood charcoal.

Dr. Percy, however, justly observes, I think, with regard to the presence of gaseous matter in charcoal as fuel, that, inasmuch as there is always an excess of hydrogen, over what is required to burn up all the oxygen, the latter must be regarded not only as water, but as water in the solid state or most disadvantageous condition, and its presence is therefore detrimental.

Dogwood being, as I have said, very readily charred, the process of charring is usually conducted at a low temperature; and wood charred at a low temperature always contains more oxygen and hydrogen in its constitution than more highly burnt charcoal. But it by no means follows that the greater violence of explosion of the powder is due to the greater amount of gas in the charcoal. No doubt the gas in the charcoal aids the inflammability; but I think that the main reason is to be found in the fact that charcoal "burnt" at a high temperature is always harder, denser, and a better conductor of heat than when burnt at a low temperature. The conductivity of heat makes it withstand the action of the heated gases, I imagine, just in the same way as the well-known conductivity of heat in copper makes it the best material for resisting the action of fired gunpowder in the bore of a gun; and its hardness prevents it from being reduced to an impalpable dust so readily as slack-burnt or under-burnt charcoal. If the latter be crushed between the fingers it is easily reduced to a fine soft dust, while the former is hard and gritty. It is therefore, I think, because the particles of charcoal are smaller and more readily inflammable that dogwood powders, more especially when the charcoal has been burnt at a low temperature, are quicker than other powders. What appears to be required, therefore, in the manufacture of fine grain powders, is that the particles shall be as fine and as close together as possible, so that the combustion may proceed with sufficient rapidity.

The question, however, may be asked, cannot the slower burning of the alder or willow charcoal be compensated for by making the grains of powder finer? I shall answer this question by a short statement of the experience of Waltham Abbey on the point. I have already referred to the change from F.G. to E.R. powder, in which dogwood was introduced, and to the change from E.R. to J. 2 or R.F.G., in which the size of grain was increased; and I may add that in the most recent manufacture of this powder, the grain is somewhat larger than in the original manufacture, while in addition the density has been increased, a quality which has the same effects to a great extent as size of grain. And now, as far as we know, no powder excels R.F.G. in shooting qualities in the Enfield rifle.

When the Martini-Henry rifle was introduced, it was found that R.F.G. could not be used, because it fouled the rifle. What was the cause of the fouling it is difficult to say, unless it be that the density of the powder was too low and its action too quick, which would also account for the inferior shooting, if we suppose that the great pressure would crush up the bullet and thus interfere with its concentricity of spin and accuracy of flight. It is to be borne in mind that the bore of the M.H. rifle is small and the bullet long, which not only very much increases its inertia, but also gives less space for the powder to expand. Hardening the bullet has better enabled it to resist the greater strain which is thus produced, but the action I have described is occasionally to be observed in the drop-shots which sometimes occur with this rifle, which probably are the result of the bullets being exceptionally soft. The fouling might, therefore, be due to the great length of the cartridge interfering with its thorough ignition with so quick a powder, in the same way as wave action exists in guns, when the powder is not suitable. I can see no reason why this action should not take place with small arms as well as with large guns, and so part of the charge remain unconsumed: and this, I think, is no doubt one cause of fouling, though it is not the only one. The want of proper lubrication by the non-expansion of the beeswax wad, and the consequent escape of gas over the base of the bullet is another. Exceeding dryness of the air and want of softening of some of the products of combustion from deficiency of moisture is a third.

In support of the notion that wave-action is a cause of fouling, I may mention that a sportsman lately told me, that when he washed out the piece after firing a very fine powder, the water became as black as ink, but that this did not occur when a coarser powder was used.

Shortening the charge by chambering has simplified the problem of finding a suitable powder, but still it has been found that it is only by increasing the charge from 70 to 85 grains, and using a very slow burning powder, that satisfactory results are to be obtained.

The Committee on Breech-loading Small Arms, in their investigations as to the most suitable powder for the H.M.

rifle, found that Curtis and Harvey's No. 6 powder gave the best results. They naturally wished to obtain a similar powder from the Royal Gunpowder Factory.

In the opinion of the Superintendent at Waltham Abbey, such powder could be produced by making the following alterations in the manufacture of R.F.G.:

1st. Charcoal burnt at a lower temperature;

2d. The charge taken off the mill bed in a moister condition;

3d. Pressed to a higher density;

4th. More highly glazed and sifted to a more uniform size of grain.*

It would appear that the way to make the best powder is to prepare the materials with a view to make the powder as rapidly burning as possible, and then to moderate the combustion by density and size of grain. If the powder be not quick burning the density very much affects its rate of burning, and, as was seen with W.A. inch cubes of high density, the powder becomes much too slow for any gun. Now it will occur to most that, as soon as the pressure rises in the bore of the gun, the density of powder remaining to be burnt becomes very much increased; and, though the powder used be of low density and consequently quick burning on that account, it will soon become a slow-burning powder. This is the condition we most wish to avoid; and, therefore, it is better to start with as high a density as possible and have it naturally-quick burning, and thus the rate of combustion will be less affected when the pressure rises in the bore of the gun.

These conditions would, I believe, hold absolutely true were it not for another feature in the burning of grains of powder which accelerates the combustion of powders of lower density, though otherwise slower burning. I refer to the porosity of the grains, on which I more particularly dwelt in a previous paper read here. With the same density of grain, powders made with hard burnt charcoal are more porous than those made with slack burnt charcoal, because, the particles of charcoal being coarser, the spaces between will be proportionately larger; and also the particles of charcoal, being denser, will occupy less space, and so leave more room for interstices. The crushing pressure of these particles also we may suppose to be higher than with soft charcoal, which will enable them to build themselves up in accidental positions, and thus give rise to uneven densities in different portions of the grain itself. Under the intense pressure in the bore of the gun the flame becomes forced into these spaces, and the less dense portions of the grain burn more rapidly than the harder portions, and thus give rise to that particular pitted and burrowed appearance of unconsumed grains of powder which are picked up after the discharge of the gun, with which we are all familiar. It is difficult to say how far the flame becomes forced into these channels, but the effect must be that from each small center of penetration the combustion proceeds more rapidly as larger and larger surfaces come under ignition, and so an increased amount of gas is generated. It is a great mistake to assume that under all circumstances the combustion proceeds in regular successive laminæ from the surface to the center of a grain of powder. With very high densities 1.82 to 1.84, when the powder probably has been subjected to a pressure equal to the crushing strain of the particles, I believe no appreciable interstices exist, and then the grain does burn regularly from surface to center. The rate of burning then depends on the fineness of the particles of charcoal, each particle requiring to be consumed before the flame can reach the next to ignite it; and this no doubt accounts for the very marked difference in burning of W.A. 1″ cubes of ordinary charcoal, and Hall and Sons 1″ cubes of dogwood charcoal. With lower densities, however, the conditions are different, and though the slack burnt charcoal still retains its greater rate of combustion, yet the greater certainty of porous channels, or unequal densities in the grains with harder charcoal enable it with more certainty to take advantage of the accelerated rate of combustion I have noted, and so tend to a great extent to reduce the difference in ultimate effect. It is mainly, in my opinion, due to this fact, that our cubical powder is able to match to so great an extent the prismatic

* Tabulated results of many experiments with powder of different brands were given in the original paper, but for want of space the writer's conclusions only are presented here.

powder used by some foreign governments.

In the prismatic powders the channels are introduced into the grains of powder intentionally, so that there may be an accelerated rate of burning from them as centers as the combustion proceeds. The manner in which these holes are made, however, renders it uncertain whether their whole surfaces are ignited, as we find with pressed surfaces that they are generally only ignited from points; and, in fact, portions of grains of powder are often picked up of which the surface never appears to have been ignited. If the holes could be bored so as to give more readily ignitable surfaces, it is probable that the combustion would be much improved. Prismatic powder has to be made of much lower density than granulated or broken powder, in order to compensate for the greater difficulty of ignition.

It will be observed with prismatic powder that the sizes of the prisms are of no consequence provided that the channels are proportionately numerous and suitably placed. And in support of this notion I have advanced that our powders are porous, I will give the following results obtained by experiment with powders of different sizes of grain with the same density. The powders were pressed in the same press-box at the same time, so it is tolerably certain that their densities were identical.

Powder.	Density.	In 8-in. gun, 35 lbs. charge, 180 lbs. projectile.				
		Muzzle Velocity.	Pressure.			Length of Cartridges.
			A	B	C	
W.A. Sept. 30, 1875. Rework		f. s.	Tons.	Tons.	Tons.	
1.5 inch cubes	1.76	1,471	16.2	15.5	15.1	20¼″
1.7 inch cubes	"	1,471	16.8	16.1	14.1	20½″
2.0 inch cubes	"	1,452	15.7	15.2	15.2	21″

If we make allowance for difference in lengths of cartridge, these three samples give almost identical results in the 8-inch gun; and when we come to the 38-ton gun the larger cubes by no means show to advantage:

Powder.	Density.	In 38-ton gun, charge 130 lbs., projectile 800 lbs.			
		Muzzle Velocity.	Pressure.		
			A	1	2
W.A. September 30, 1875. Rework		f. s.	Tons.	Tons.	Tons.
1.5 inch cubes	1.76	1,460	26.1	27.7	19.7
1.7 inch cubes	"	1,440	27.3	26.5	24.5
2.0 inch cubes	"	1,409	28.7	24.5	22.5

Description.	Density.	38-ton gun.			
		Muzzle Velocity.	Pressure.		
			A	1	2
W.A. December 2, 1875. Rework		f. s.	Tons.	Tons.	Tons.
1.5 inch cubes	1.81	1,396	22.2	22.2	21.2
1.7 inch cubes	"	1,330	17.6	17.0	17.2
2.6 inch cubes	"	1,350	15.0	13.7	15.2

Take, however, the following samples of powders of equal but higher densities, and the effect of size of grain is very marked:

(*See last Table on preceding page.*)

Both of these sets of samples were made from rework L.G., with the same description of slack burnt charcoal. I have already compared the latter 1-7 and 2-inch specimens with those of W.A., February 5th, 1876, of lower density made from new materials where the charcoal is more burnt. It will be observed that, with the February 5th, 1876, specimens, the pressures do not go by size of grain, showing that the powder is porous owing to the low density; and, as already stated, though the velocities are about the same as in the last samples given, the pressures are higher, which bears out my theory about the higher densities and quicker burning materials giving the best results.

Of course I do not give these samples as *proving* the question, but merely as illustrations of the features I wish to bring before you. We have had samples, especially those made by Messrs. Hall and Sons, of Faversham, of powders of low densities and hard-burnt charcoal which have given the very best results. They have been tried, however, with powders only 1″ cubes, and density 1-75, giving results too quick for the 38-ton gun with large charges.

This leads me to the consideration of the third and last feature I wish to lay before you. I believe the action in that case to be modified by the slow burning of the particles of charcoal themselves, these particles being so large and dense that, if we suppose an extreme case, all the particles may be ignited very rapidly, but the mean time of burning of the charge depends on the burning of a single particle. Charcoal has never been burnt at Waltham Abbey to an extent so as to produce this result, so that I am unable to give any accurate data as to how far this method may be carried out on a large scale. But I think it is worth investigation.

I may now sum the different features in powders for large guns, by which the rate of burning may be modified.

1. A quick burning powder, with a high density, and no appreciable porosity.

2. A moderate burning powder, with a moderate density, leaving moderate porosity.

3. A very slow burning powder, with very large porosity.

Powder may be produced to give very good, and possibly equally good, results, by any of these methods, but, I think, probably it can be produced best and with greatest certainty by the first method. It is, however, by far the most expensive, owing to the greater time required to manufacture.

The second method, with a slight tendency towards the first, is that by which powders have hitherto been made at Waltham Abbey. It is the cheapest, but it depends to a great extent on the most uncertain of all the qualities, viz., porosity. The only means by which this uncertainty can be neutralized is by systematic proof and careful mixing. When this is properly carried out, the results can be relied on with perfect certainty.

In all cases size of grain is a most important element which can never be dispensed with, owing to the facility which it gives for the complete ignition of the charge, and the total elimination of wave action, which is so very destructive to the bore of the gun. From observation of the good results which were obtained by Hall's inch cubes in the 8-inch gun, I was led to suggest the trial of 2-inch cubes for the biggest guns, for, if we double the diameter of the bore of the gun, we ought also to double the length of the side of the cube of powder required for it. With such large grains no wave-action is now to be observed even if the charge be ignited in rear. It is, therefore, a safe and sound principle to keep the grains as large as possible, provided other qualifications are not unnecessarily sacrificed. Were, however, our heavy guns breech-loading, the result of my observations lead me to believe that, if the cartridge were ignited along the whole centre from the rear, smaller grain and denser powder could be safely used, and greater efficiency thus obtained.

I may mention a difficulty which has been encountered in the manufacture of these large cubes. In glazing in the ordinary manner, it has been found that the amount of heat generated is not sufficient to make the powder sweat in the glazing barrels. The portions thus rubbed off are not pasty enough to adhere to the sides of the barrel, but remain in a state of dust, which adheres to the cubes, and requires to be removed before the powder is finished and black-leaded. It is anticipated that, by using one large instead of four small glazing barrels, not only will this objection be removed, but larger units will be obtained for the after process of mixing. The system of mixing, and proof of pebble-powder, I have explained in a previous paper. It is obvious that if a sample of 130 lbs. of cubical powder be fired from each batch, the batches must be large to prevent an unnecessary expenditure of powder. By adopting a unit of 1,600 lbs. instead of 400, as in the case of pebble-powder, a batch of 16 times 1,600 lbs. can be obtained if four ordinary stovings be reserved before the powder is finished. For this purpose a finishing reel, to contain 1,600 lbs., has also been made. Cubical powder will not pass through a hopper in the same way as pebble-powder, because the grains are so large, but, by means of this mixer, it is anticipated that, if required, as many as 16 different batches can be made uniform, by taking a barrel from each for a run.

I trust that the remarks which I have now submitted to you, will show how deeply interesting and important this subject is, and how steadily and surely light has dawned on us, with the aid of the proof tests, which were inaugurated and carried out by the Committee on Explosives. I have had the opportunity of studying the matter for now nearly five years, during perhaps the most interesting period; and I hope it may not be considered inappropriate to have laid the results of my observations before you. Though many of the deductions I have drawn are merely my own theories, they are the fruit of long and careful study, and they will not, I feel confident, be lost sight of by those who have to do with powder at Waltham Abbey, or elsewhere.

HYGIENIC STUDIES ON THE ABSORBING POWER OF SOILS.

By Dr. LISSAUER.

From "Deutsche Vierteljahrsschrift," through Proceedings of Institution of Civil Engineers.

In experiments hitherto carried out in connection with this subject, the samples have been taken by simply digging them from the ground with a spade, a plan which does not permit of the soil being examined in its natural state; and it is clear that its absorbing power mainly depends upon the relative position of the particles of earth to one another. To overcome this difficulty the author used a tin cylinder, encircled by an iron case made in two halves, so that it might easily be removed, and furnished with a circular steel knife at one extremity and a stout handle at the other. By thrusting this apparatus into the ground, and then withdrawing it by means of the handle, the cylinder could be filled with a sample of soil in its natural condition. By then removing the iron case and fastening a perforated cap to the lower end of the cylinder, it was possible to filter liquids through the sample without in any way disturbing it.

The results of fifty-one experiments made with this apparatus point to the following conclusions:

1. The liquid entering the pores of the soil displaces the air or liquid previously present, forcing the former upwards into the atmosphere, and the latter downwards into the subsoil or effluent water.

2. In order that the effluent water may not be directly polluted by the sewage liquid, the maximum supply of the latter must not be more than can be taken up by the pores of the soil.

3. Dry loamy soil absorbs more than peaty soil and gives up less, whilst dry sandy soil on the contrary absorbs less and gives up more. Consequently a loamy soil, though it absorbs a large quantity of liquid, can seldom be irri-

gated; whereas a sandy soil, though it absorb but little, may often be irrigated.

4. The looser the soil the easier water-courses are formed in it, and therefore the less can its maximum power of absorption be approached, otherwise the sewage liquid might penetrate the subsoil before the whole of the ground had been saturated.

5. In order, therefore, that the effluent water may be protected from pollution, it is especially necessary that the absorptive power of the soil should be known; but the determination is of no value unless it be made in a sample in which the natural position of the particles of earth have been undisturbed.

6. Having determined how much fluid a cubic yard of the soil can take up, and therefore how much is necessary for the daily supply of sewage liquid, this is to be multiplied by the number of days which must elapse before the organic matters present in the liquid shall have been destroyed. As a criterion of this, it is sufficient to ascertain if after all free ammonia has been expelled, any more is formed on burning with soda-lime; but in making use of this test of course any nitrates or nitrites that may be present must be taken into account. This period of time should be determined by special experiments at different times of the year and under different systems of cultivation.

7. The presence of such non-nitrogenous organic acids as arise from regressive metamorphosis cannot serve as an indication of the impurity of the effluent liquid, since when once formed they remain unchanged for a long time.

8. Having determined the cubic amount of earth which is necessary for the available supply of sewage liquid, some means must be taken to guard against the fluctuations of the effluent water by drainage. It is therefore recommended to add at least ½ yard to the depth as reserve soil, for the protection of the effluent water from such accidental disturbances as rain or the formation of water-courses.

9. Suspended matters only then pass through the soil when, like Bacteria and Monads, they are smaller than its interstices and specifically lighter than the sewage liquid.

10. The suspended matters which are specifically heavier than the sewage liquid are retained by the soil, making it closer and increasing its power of absorption.

11. The absorptive power of a soil depends upon its character, and also to a great extent upon the degree of concentration of the liquid used. Unless, therefore, the determinations are made with solutions of equal strength, they lead to false conclusions.

12. As the result of four years' irrigation at Heubude, the absorptive power of the soil has been more than doubled.

13. The absorptive power of a soil for urea is very much increased by vegetation; but however high it may be, the soil never withdraws the whole of the urea from a liquid; some of it always remains in solution.

14. The effluent water of an irrigation works ought not to be compared with good drinking water, since it must nearly always contain some ammonia; often nitrates and nitrites, and always a certain amount of chlorine, which is almost completely unabsorbed by the soil.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—Among the valuable papers recently presented to the Society are: Reconstruction and Enlargement of Cork Run Tunnel, on the Pittsburgh, Cincinnati and St. Louis Railway, M. J. Becker; Notes on the Masonry of the East River Bridge, F. Collingwood; The Rate of Set of Metals subjected to Strain for considerable Periods of Time, R. H. Thurston; Co-ordinate Surveying, H. F. Walling.

The American Institute of Mining Engineers.—The last volume of the transactions is full of the most valuable matter.

It may safely be put in competition with similar journals anywhere in the world for the first place. We reproduce from it in the present number of this magazine, an article by Prof. J. C. Smock.

The semi-annual meeting is about to begin its session in this city, and more valuable additions to the science of mining metallurgy may confidently be expected.

IRON AND STEEL NOTES.

Mr. Attwood's Patent for Manufacturing Steel.—The Judicial Committee of the Privy Council have granted an extension of Mr. Charles Attwood's patent for "improvements in the production of steel and iron of a steely quality," as owing to the peculiar character of the trade the patentee and his representatives had not been reimbursed for the great expenditure of time and money which had been necessary. The late Mr. Attwood took out his patents in 1862 in several countries, and it was submitted to the Court that before that time steel had been made by the cementation process, which was a costly one, and also of long duration. Mr. Attwood's method, however, altered this, for steel of any desired quality could be produced in a few hours by one operation. To carry out the process, Mr. Attwood erected works at Towlaw, at considerable expense and trouble, but they were profitless, and had to be dismantled in 1863. At Wolsingham afterwards he laid down another establishment, and though he sold a large quantity of steel, the great expense of developing the process made it a source of loss. Since 1872, it had, however, realized a profit. It was this year beginning to reap a fair reward. Mr. Wm. Baker, of Sheffield, and others, bore witness as to the value of the invention.

Mr. Bell's Improvements in the Manufacture of Iron.—The particulars of this invention have been published by the Patent Office, from which it appears that he proposes to make puddled iron from pig iron formerly unsuited for it. He says it has hitherto been found impracticable to obtain a malleable product in the Bessemer converter, or from Siemens-Martin furnaces from certain qualities of pig iron, and he takes such iron as it comes from the converter or furnace, adding to it spiegel iron, and transferring it into a puddling furnace, where it is worked either by manual labor or mechanical means. The following statement by Mr. Bell, explains exactly how he proposes to proceed:

In the substitution of mechanical for hand puddling in furnaces known as rotary, considerable difficulty has been experienced in preserving, from the action of the heat, the lining which serves among other purposes as a protection to the iron casing of the structure itself. In a great measure, I believe this action to be due to the presence of silicon in the pig iron under treatment, which, being oxidised during the operation, attacks the oxides of iron constituting the lining in question.

My process consists in submitting crude iron intended to be used in such furnaces as those described, by preference from the blast furnaces direct to the action of a current or currents of air. This is easily effected in a piece of apparatus known as the Bessemer converter. The extent of which this operation has to be carried will depend on the quantity of silicon contained in the pig iron. When this amounts from $1\frac{1}{2}$ to 2 per cent., I find five minutes' exposure to a blast of 15 to 20 lbs. on the square inch will suffice.

When the metal has been blown to the extent desired the metal is passed, by preference it is run direct into the rotary puddling furnace, and puddled.

In place of stopping the blowing operation whilst the iron still contains sufficient carbon for puddling, the blowing may be carried further, and the carbon afterwards replaced by adding spiegel iron or other pure cast iron rich in carbon; this, however, adds somewhat to the cost of the process.

It often happens that the relative quantities of silicon and phosphorus in pig iron are such that, before the former can be sufficiently oxidised, the carbon it contains is burnt off to an extent which interferes with the subsequent operation of puddling. In such a case, the iron in the puddling furnace comes to nature, as it is termed, before the phosphorus is properly acidified and removed by the oxide of iron always present. When, therefore, it is desired to obtain malleable iron as free as possible from phosphorus, I find it useful to prevent the too rapid expulsion of the carbon by blowing into the converter, along with the blast, carbonaceous matter, such as ground coke, charcoal, or other similar substance; or, as already explained, the carbon may, after blowing, be replaced by adding spiegel iron or other pure cast iron rich in carbon. On the other hand, where malleable iron of a hard character is required, I continue the blast until more or less of the carbon of the pig iron is expelled, by which means the metal retains more or less phosphorus, which imparts to it the property of hardness or cold-shortness, as it is termed.—*Journal of Iron and Steel Institute.*

RAILWAY NOTES.

Turkish Railways.—The last two great wars on the Continent have sufficiently demonstrated the great value of railways for operations in the field. On that account it will be interesting to note the railway resources of the Balkan Peninsula, which may at once be said to be greatly deficient in this respect. There are no lines of railroad at the seat of war and in its immediate neighborhood, and thus the removal of troops from one scene of operations to another, depends entirely on the marching powers of the troops engaged, which, as we know, up to the Crimean War always regulated their movements. Turkey for the first time now uses the few railways at her disposal for transporting her forces from distant provinces. Since the extent and importance of those several lines are not generally understood, it may not be out of place to enumerate the few railway communications at the disposal of the Turkish commanders. There are five railway routes in European Turkey, all independent of each other, and having no junctions with foreign railway systems, with the exception, perhaps, of the line from Varna to Rustchuk, joining here the Roumanian system of railways. The most eastern and shortest of Turkish lines leads from Kustendje, on the Black Sea, to Tchernavoda, on the Danube; the second from Varna, on the Black Sea, past Schumla over Rasgrad to Rustchuk on the Danube, where it joins the Roumanian railways. The third and longest line, the Roumelian Railway, leads from Constantinople over Adrianople and Philippopoli to Sarembey, there branching off along the Maritza to Dede-Aghatch, on the Ægean Sea, and is intended to be extended beyond Sofia. The fourth line, which, besides the last-named, has lately been most used for the transport of troops, starts from Salonica, and ends at present at Mitrovitza, but is destined to form the connecting link with Hungary and Austria, and thus to become the most convenient and direct line of communication of the East with the West. The most simple network of railways will only be completed when the Roumelian Railway is joined to the Salonica-Mitrovitza line, and the latter to the Austro-Hungarian railway systems. Only then will this line, which will afford uninterrupted communication between Paris and Vienna and Constantinople, become of importance. The reason why this undertaking has not yet seen its completion is found in the miserable quarrels of the Turkish Government with Baron Hirsch, the railway contractor. The line of junction most easily to be constructed would lead through Servia, while Turkey wishes to see the railway continued through her territory, namely, the Herzegovina and Bosnia, although those countries must offer the greatest difficulties to railway construction on account of their extremely mountainous nature and sparse population. The Turkish Government has constructed already a short line in Bosnia, the fifth in our list, leading from Doberlin over Novi and Priedor to Banyaluka, destined to form an intermediate link between the Roumelian and Austro-Hungarian railways. Servia does not possess a single line of railway; and only one Hungarian line, that from Temesvar to Bazias, has its terminus on the opposite bank of the Danube; Belgrade itself being still dependent on stage-coach and river communications. The construction of Servian railways was, however, almost as good as secured, and had not the war intervened, would have commenced in a few months. Roumania has an extensive system of railways, nowhere, however, on account of the intervening Carpathian Mountains, joining the Hungarian railroads. Greece has at present only one short line, the railway from Athens to the Piræus; and it need hardly be mentioned that Montenegro has no railways, and probably never will possess any.

A Railway in China.—The Celestial Empire has at length become the scene of railway operations, and, although only on a small scale at present, it leads to the hope that the present may prove the precursor of many lines. The question has been agitated for some years past, the Chinese proving very difficult to be persuaded of the advantages of the railway system. In 1873 it was proposed to subscribe for a short line of railway which was to be made and presented to his Majesty the Emperor. The scheme was well supported here, and was warmly discussed when the Iron and Steel Institute visited Liége in 1873. At that time Mr. R. C. Rapier, of the firm of Ransomes and Rapier, of Westminster and Ipswich, had a special audience of the King of the Belgians upon the subject, and the leading members of the English and Belgian iron trades gave their adhesion to the project. But it fell through on account of political reasons which interfered to prevent the consummation of the plans. There were, however, some gentlemen who were moving in another direction at the same time, and with the same object—that of introducing railways into China. These were Messrs. Jardine, Matheson, and Co., of London and Shanghae, who, with their friends in both countries, had purchased land for a carriage road from Shanghae to Woosung. The notion of a railway, of course, soon occurred to them, and they had estimates made for a line between those points, which are 10 miles apart. The estimates however were high, and as there was a risk attending the investment, the project of an expensive railway was abandoned.

So far Messrs. Jardine's scheme. Messrs. Ransomes and Rapier still clung to to the belief that an opportunity would offer for the introduction of railways in China, and they constructed a small locomotive—the Pioneer—which they intended to send over, when practicable, to demonstrate the feasibility of a locomotive railway. The opportunity in time offered for placing it upon Messrs. Jardine's proposed line, and it was forthwith sent to China. That arrangement having been settled, Mr. Rapier prepared the estimates for a cheap line of railway with a 2 ft. 6 in. gauge, and a station at Kangwan, a point midway between the two termini. The estimate was £30,000 and the contract was let to Mr. John Dixon, of London. The line was commenced in January 1876, and has been constructed from Shanghae to Kangwan—half its length—and thus far it was opened on the 30th June last. The remainder of the line is well advanced, and is expected to be opened in a short time. The line was easy to make, being unattended with any engineering difficulties whatever. It is laid with 27 lb. rails of the Vignoles section, on cross sleepers. The little engine Pioneer was specially built to be the smallest practicable engine to travel 20 miles an hour or to haul 20 tons. The cylinders are 5 in. diameter with a 6 in. stroke. The engine is carried on four wheels 18 in. in diameter, all coupled and all fitted with brakes, the wheel base being 2 ft. 6 in. It has 35 square feet of heating surface and 1 square foot of grate area, and its weight in working order is 30 cwt. This engine has most completely succeeded in effecting its intended purpose, that of disarming the prejudices of the Chinese, the engine performing really appreciable work, and yet being so small as to cause any opposition to appear quite ridiculous. This primary difficulty was overcome during March and April last, and the larger-sized engines for working the line arrived out in May last, ready for the opening.

These latter engines are two in number, and have been respectively named the Celestial Empire and the Flowery Land. These locomotives were designed by Messrs. Ransomes and Rapier, by whom they were also manufactured. The type of engine was determined on to suit the local circumstances of the line, high speed being of less consequence than good hauling power. The length of wheel base is 7 ft. 6 in., and the wheels, 2 ft. 3 in. in diameter, are six in number, all coupled and fitted with brakes. The cylinders are 8 in. diameter by 10 in. stroke. The barrel of the boiler is 2 ft. diameter, the tubes being $1\frac{3}{4}$ in. diameter and 6 ft. long. The total heating surface is

150 square feet, and the grate area 4 square feet, the weight in working order being 9 tons. The water is carried in side tanks. The boiler and frame are throughout of Low Moor iron, and the boiler is constructed for a working pressure of 200 lbs., but it is intended to be used only up to 120 lbs. This excess of strength of the boiler is to meet any contingencies that may arise at the hands of the Chinese firemen. The railway is fitted with double water-supply tanks at each end of the line, so as to allow the water in all cases one day to settle. In order to fully cover the liability of being short of clean water, the water tanks of the engines are made large enough to run two double trips. Before being sent away these engines were fully tested at Ipswich to four times the maximum duty which they are ever likely to be called upon to perform in China. The trips which these engines have to run being short, the fire will often be brightest at the end of the journey, and the stoppages being long, the engines are provided with extra steam space by having both a high-topped fire box and a dome, and are also furnished with an extra large Gifford's injector, so as to fill up the boiler quickly when standing. The feed-pump is also of extra size. The frames are $\frac{3}{4}$ in. thick, and planed all over, the axle-box guides being of wrought iron and rivetted on to the frame. The springs are hung underneath the axle-boxes. The wheels have steel tyres and Low Moor axles. The engines are fitted with all the usual appliances, and have throughout been made with special care, having regard to their important destination. The carriages are first, second, and third-class, of substantial construction and plain but neat appearance.

ENGINEERING STRUCTURES.

THE WATER SUPPLY OF LYONS.—Previous to 1854 Lyons was supplied by water pumped direct from the Rhone and from private wells; about 55,000 gallons daily being drawn from the former source. As the supply was quite insufficient it was determined at the above date to eek, by the advice and under the direction of M. A. Dumont, an engineer of the Ponts et Chaussées, an increased amount by driving in the water-bearing gravel bed, which fills the center of the valley of the Rhone, and upon which the lower portions of the town are built, filtering galleries and reservoirs, whence the water might be pumped for distribution to the different quarters. A covered filtering gallery about 130 yards long, and a little over 16 feet wide, was then driven near the town on the right bank of the Rhone; it was built with solid sides admitting water only upwards through the floor, which was placed at 10 feet below the standard average low water mark of the river. A filtering basin was connected with this gallery to catch the water coming from it, 144 feet long by 125 feet wide, with the sides pitched and slopes of 1 to 1; it was arched over in spans of 14 feet 9 inches in the clear. Several similar filtering galleries and basins were added later on, as the demand for the water increased, till about 7,700 square yards of effective filtering surface was obtained. It was anticipated that this would yield during twenty-four hours about 9,000,000 gallons, or at the rate of about 1,200 gallons per square yard of filtering surface: however, it was found that when the river was low it was with difficulty that 6,500,000 gallons were obtained. Of late years the population of the town and the area supplied with water have increased very rapidly; and it became a question of much moment how to meet the augmented demand. On examination it was found, that, owing to the level of the invert of the filtering galleries, and to the existence of hard beds of conglomerate around them, no very greatly increased supply could be expected even from a very much larger filtering surface of galleries. It was, however, ascertained that underneath, below the conglomerate beds, there existed a fine, porous, bed of gravel; and it was finally decided to sink down a number of wells from the floor of the filtering galleries into this water-bearing strata. During the course of last year seven of these, 6 feet 6 inches inside and 26 feet deep, were sunk; they are octagon shaped and lined with cast iron framing. These wells have given very satisfactory results, yielding nearly 400,000 gallons each during twenty-four hours. With their aid there is no difficulty in affording the present average daily supply of nine million gallons, or about 25$\frac{3}{4}$ gallons per head; and also, it is anticipitated, in meeting further demands. The distribution of this water to the town of Lyons, built at very great difference of level and extending over an area of 11,000 acres, was a matter of some difficulty. For this purpose Lyons is divided into four districts: (1) the low level; (2) the high level; (3) the heights of Fourviere; and (4) the park on the other side of the Rhone. The low level service has four pumping engines, three of them Cornish, of 170-horse power each, with steam cylinders 3 feet 3 inches in diameter, and 8 feet 2 inches stroke; the remaining engine being double-acting, of 135-horse power. In case of need these engines, if working together, can raise 17,000,000 gallons in twenty-four hours; they deliver into a service reservoir at Magnoles at about 160 feet above the filtering well. The high level district has two direct-acting engines of 135-horse power each, which deliver into a reservoir at Montessuy, 315 feet above the well. The heights of Fourviere have a reservoir 197 feet higher than the last, or 512 feet above the filtering well, with a small 30-horse power engine to supply it. The detached service of the Park is performed by a 35-horse power engine pumping into a reservoir 118 feet above the low water level of the station. The water supplied is soft, clear, and of excellent quality; it is alkaline and also rich in carbonic acid; its average temperature at the well is 63 deg. Fah.

WIRE TRAMWAYS.—Notwithstanding the general dulness which has for some time past pervaded almost every department of trade, both at home and abroad, there are a few branches of business in which more or less briskness is apparent. These are mostly cases of perfecting plant and appliances designed for use in the revival hoped for, with some reason, as likely to come before long. Noteworthy among them is the fitting up in many quarters of Hodgson's useful system of light goods carriage by means of a "wire tramway," as carried out by Mr. Carrington, which, we are informed, has been steadily extending itself in all parts of the world. Several hundreds of miles are now in operation, a considerable portion of which has been erected during the last two years. Many improvements, lately invented, have been introduced, consisting chiefly in the minor working details, which, though insignificant in themselves, have largely contributed, in conjunction with the especial care taken in the manufacture of the plant, to the very successful results which the more recent tramways have given. One improvement, which has had the effect of greatly extending the application of the system, consists in the use of a peculiarly-formed grip, by means of which the loads can be made to adhere to the wire rope to such an extent as to ascend or descend inclines as steep as one in three without slipping. It will at once be seen how, with such capabilities, the tramways, instead of taking circuitous routes in order to obtain an incline of not more than one in six, the original limit, can now be laid in a direct line, passing up the sides of hills which otherwise would prove impracticable. In cases where ravines occur, too wide to allow of the ropes being stretched across in the usual way, the tramway can now descend the sides. A good example of a wire tramway working on a steep incline may now be seen daily at work at the flannel works of Messrs. Butterworth & Co., near Rochdale, where it is employed to carry coal from the mine situated at an elevation of about 500 feet. The line is laid direct from the mouth of the mine to the boilers of the factory, and is about 500 yards in length, thus descending at the rate of about one in three. The coal is carried in loads of one and a half cwt. in wooden boxes, and, owing to the great incline, no power is required to keep the rope in motion. A quantity of five tons per hour is transported, and only the labor of two men is required. Similar lines are in operation at the works of Messrs. Norton Brothers (limited), near Huddersfield, where the tramway in its course passes over a great part of the works, and carries the coal direct from the pit mouth to the boilers, it being filled from the pit corves into the tramway buckets by means of a hopper and a slide, which enables one man to do all the work required. This tramway derives its power from the mill shafting. Another useful application has been made at the sugar works of James Duncan, Esq., for the purpose of carrying coal from the side of the Thames, where it is brought in barges, to the interior of the works, a distance of about 150 yards—throughout its course it passes over the various buildings and roadways, which are now left free for the regular traffic of the works—the cost of carriage of the coal at these works has been greatly reduced by the use of this tramway.

Ano her and very valuable application of the system has been for the construction of a cheap means of shipping or unshipping materials at a distance from the shore, where the length is too great to admit of the erection of a pier. The tramway terminal, in such cases, is attached to a group of piles placed in deep water, and the ropes are supported on wood posts placed at intervals of about sixty yards between the terminal and the shore—thus practically forming a pier without the great expense of a continuous platform. Advantage may be taken, in such cases, to transmit power from an engine situated on the shore to the pier-head or sea terminal by means of the wire-rope, which, at the same time, can also be carrying the loads from the shore to the ships, or *vice versa*. Cranes on the sea terminal can thus be erected for unloading by means of the power placed on the shore—a great desideratum when the power is available from a factory, or is used for other purposes, or where the roughness of the sea renders it unwise to put a costly engine and boiler at such an exposed place as the sea terminal would be.

An example of such a tramway is in operation at the mines of the New Zealand Manganese Company, where it carries the ore from the mines about half a mile inland, and at an elevation of about 250 feet to a sea terminus situated 1,200 yards distant from the shore, in a depth of fifteen feet of water. This terminal is made out of the hulk of an old steamer, securely moored in position, and between it and the shore about twenty posts are placed, which support the ropes and buckets as they travel from the mine to the ships. This tramway has been in operation for some time, and has greatly reduced the cost of carriage and shipment. Another tramway of a similar nature is now in course of erection at St. Vincent, in the Cape de Verde Islands, for the coaling depot of Messrs. Cory Brothers, of Cardiff. Wire tramways are also now extensively used for sugar-cane estates, where they present some special advantages not possessed by any other system of transport. To these and many other special applications of the system we may refer in a future number.

ORDNANCE AND NAVAL.

THE NEW AUSTRIAN IRONCLAD TEGETHOFF. —A brief summary of the characteristics of this important ship, now under construction at Trieste, as the latest embodiment of Austrian naval opinion, will be interesting to our readers. We may mention that she is, in a peculiar degree, the embodiment of naval opinion in Austria, inasmuch as her design is the consequence of the prolonged inquiries and deliberations of a very carefully selected Committee which sat for several months at Trieste, although Herr Romako, the Chief Constructor of the Vienna Admiralty, is no doubt personally responsible for the technical details, and for the calculations of the ship. In a paper presented to the Institution of Naval Architects a few weeks ago, Mr. Reed gave the following general dimensions and particulars of her: "Length between the perpendiculars, 286 feet 11½ inches; length, total, 303 feet 1½ inches; breadth on the water line, 62 feet 9 inches; extreme breadth to outside of armor, 71 feet 1½ inch; depth of hold, 34 feet 9 inches; draught of water, aft, 26 feet 7½ inches; draught of water forward, 23 feet 1 inch; displacement with the half of provisions, 7,390 tons; area of the midship section, 1,301 square feet; area of the load water-line, 14,308 square feet; height of metacentre above centre of gravity of displacement, 14.623 feet; height of metacentre above water, 4.770 feet; distance of the centre of gravity of displacement before the midship section, 0.356 feet; depth of the centre of gravity of displacement below water, 9.853 feet; co-efficient of displacement, 0.582 feet; co-efficient of water-line, 0.782 feet; co-efficient of midship section, 0.82 feet; displacement of an inch immersion at the load water-line, 34.47 tons; weight of armor and backing, 2,160 tons; the armament consists of six 11 inch Krupp guns. Area of sails 12,165 square feet; cost of hull, estimated, £172,790; cost of engines and boilers, estimated, £81,715; nominal horse power, 1,200; number of cylinders, 2; diameter of cylinder effective, 125 inches; length of stroke 4 feet 3 inches; Griffiths propeller, diameter, 23 feet 6 inches; pitch, 24 feet; number of blades, 2; revolutions per minute, 70; number of boilers, 4; area of fire-grate, 850 square feet; heating surface, 25,500 square feet; superheating surface, 1,800 square feet; pressure of steam, 30 lbs.; number of furnaces, 36; mean indicated horse-power, 8,000; speed, estimated, 14 knots. From these figures it will be seen that although we are not dealing with a ship of the Inflexible (English) or of the Dandolo (Italian) type, in which armor of excessive thickness is placed over a central citadel of extremely limited extent, we nevertheless have a very powerful ship indeed, with armor of apparently about 13 to 14 inches thick, and with a concentrated battery of six 11 inch Krupp guns, each weighing, I presume, about 27 tons. The ship has a belt of armor extending from the stern to within about 30 feet of the foremost perpendicular, where it terminates in a transverse armored bulkhead, and a stout iron deck going forward to the stem at about 7 feet below water." The Tegethoff has a long projecting under-water spur—it projects 9 feet from the stem at the load water-line, and 19 feet from the stem-head. Nearly all double curvature is excluded from the armor plates. The battery is of the projecting type adopted by Mr. Reed in the upper decks of the Audacious class, and on the main decks of the German and Chilian iron-clads designed by him. The battery is traversed by a bulkhead which cuts off the two foremost battery guns from the remainder, after the plan adopted by Mr. Barnaby, in the Alexandra. The ports are thrown back from the outside of the side, as explained in a previous paragraph.

KRUPP'S ARMORED GUN.—" The future belongs to iron," is the dictum of engineer officers, when speaking of the principal which will have to guide them in the construction of new fortifications. The solution of the question of iron armor, however, seemed yet to lie in the distant future, until it has suddenly been brought into prominence by the latest invention of Krupp—an armored gun. The models of this piece of ordnance, according to the *Cologne Gazette*, have been submitted to the German War Office, our contemporary expressing the opinion that, considering the simplicity and evident usefulness of the system, it will be introduced in Germany. The problem which has awaited solution for years, but which has hitherto not been satisfactorily solved, the removal of the recoil of heavy guns, seems at last to have been finally settled for seige, coast, and naval guns. The gun, when fired, remains fixed in its original position, without necessitating a complicated carriage. As the name indicates, we have to do here with an intimate connexion of armor and gun. A sphere is screwed round the muzzle of the gun, any piece of ordnance being easily adapted to it, fitting exactly into the socket joint of a fixed armor plate. The trunnion of the gun rests in a simple iron carriage provided with rollers running on circular rails. These rails, in connection with the socket joint, permit of the requisite lateral pointing of the gun. The thickness of the armor ought to correspond to the calibre of the gun.

At first, many theoretical objections offered themselves to the plan, the inventor of which is Herr Krupp himself. It was predicted that the sphere would be torn off, the gun would burst, the armor plate would be injured. The practical trial has given quite an opposite result. Although it is the intention of the inventor of fixing in this manner heavy seige guns, experiments have as yet been made only with the German 8.7-centimetre (3½ inch) field gun. No less than 203 rounds were fired with a powder charge of 3 lbs. 5 oz., and a projectile weighing 15 lbs., without the armor plate or the barrel of the gun showing the slightest injury. Even the thread, exposed to so much strain, holding together the sphere and the muzzle, had not suffered. The sphere could be screwed off as easily after the firing as before commencing it.

The most important advantage of the new construction consists in the gun remaining in the same fixed position throughout the firing. If once pointed, relaying at each shot is entirely dispensed with, and it consequently permits a rapidity of fire not to be attained with other guns. In firing sixty rounds in fifteen minutes, a remarkable and highly satisfactory result was obtained. The target showed that it had been hit by the sixty shots within a narrow compass on its left side, although the distance was 1,663 yards, and the gun had only been once pointed at the beginning of the experiments, the firing having been continued to the end without once stopping for relaying. The minutes of the trial were signed by a number of foreign officers present, who expressed their surprise openly, at the unparalleled results obtained.

The importance of the invention is no doubt very great. The size of the embrasures, always welcome targets for the enemy's fire, is reduced to a minimum, viz,, the bore of the gun. Of the latter, consequently, only the muzzle, or a small part of the muzzle hoop, may be hit, if the latter by excessive lateral pointing projects somewhat outward out of the socket-joint. The gunners are perfectly protected against shell, and against shrapnel a cover of sufficient strength may easily be provided. The stability of the gun also greatly facilitates serving it, fewer gunners being required. The gun, finally, requires less space. The invention is of special importance for casements. The accumulation of smoke which hitherto has made, after a few rounds, a prolonged stay in the casements insupportable, and required a special construction for taking off the smoke, is prevented, for the smoke must remain outside.

The printed *resume* of the trials hitherto made with the armored gun, states as follows: "The possibility of rapid firing as well as the complete cover provided for the gun and gunners, render armored guns perfectly indispensable for coast, fortress, and naval artillery; and even the artillery of the besiegers will have to make use of armored batteries of this system, in order to compete with the armored guns of the besieged. Of course, the armor provided for siege batteries must be easily taken to pieces and transported." This is nothing less than iron armor for besieged and besiegers, or a complete revolution of the mode of carrying on sieges, and of constructing fortifications.

Extensive trials are to be made shortly with a 15-centimetre (6-inch) gun, to which also the chief German officers are to be invited. At the same time experiments are to be carried on *against* armored guns, for the purpose of determining what chances there are for the beseiger of disabling a gun thus protected.

Should the new construction be found efficient also for heavy guns, the advantages to be gained by its introduction will be reaped again by the cast-steel foundry of Herr Krupp; for only his (the Broadwell) system of gun and his material can be used in the construction. His system: that of breechloading in opposition to muzzle-loading, as still patronized by England. His material: cast-steel, because the other materials for ordnance are not equal to the strain exerted on the barrel of the gun as required by the system of armored guns. We need scarcely say we do not fully share the opinions expressed by our contemporary.

With the introduction of the armored gun, consequently, an obstacle would be placed in the way of those who still desire to employ another material than cast-steel in the building up of guns.

BOOK NOTICES.

An Elementary Treatise on the Differential Calculus. By Benjamin Williamson, M.A. London: Longmans, Green & Co. For sale by Van Nostrand. Price $5.25.

This is the third edition of this excellent work. As a text-book it takes the foremost rank.

A chapter on Roulettes, and a note on the Cartesian Oval, are among the additions to the former editions.

Les Terres du Ciel. Par Camille Flammarion. Paris: Libraire Academique, Didier Co. For sale by D. Van Nostrand. Price $4.00.

This work is similar in character to the well known "Heavens" by Guillemin.

All the latest discoveries regarding the different planets or planetoids of the solar system, are presented in an attractive form. The illustrations although fewer in number than in other works of its class, are excellent in character, and abundant enough for the purpose.

The volume is a royal octavo of six hundred pages.

A Text Book on Surveying. For the use of the Cadet Midshipmen at the U. S. Academy. New York: D. Van Nostrand. Price $2.00.

This work is a production of the joint labor of several naval officers of the departments of Astronomy, Navigation, and Surveying, of the U. S. Naval Academy, at Annapolis. It is designed especially for a text book in that institution, and consequently will prove of value to students elsewhere, only so far as certain specialties of surveying, incident to inland work, are better treated here than in most surveying text-books.

The subjects presented are, in their order: The Instruments; Bases; Triangulation; Plotting the work; Determination of heights; Hydrographical Surveying; Tidal Observations; Tides; Practical Hints; Projections; Running Survey; The Portable Transit; The Zenith Telescope.

As a supplement to the treatises on Land Surveying, this work will prove exceedingly valuable in scientific schools.

Such topics as Triangulation, the adjustment and use of the Zenith, and the Portable (astronomical) Telescope, Tidal observations, and Projections of Geodesic Surveys, are valuable to all surveyors, and are nowhere else so consisely yet thoroughly treated.

Practical Treatise on the Properties of Continuous Bridges. By Charles Bender, C. E. New York: D. Van Nostrand. Price 50 cts.

This is the most recent addition to the Science series (No. 26.) Mr. Bender was the author also of No. 4, "The Proportions of Pins used in Bridges."

The present work was produced under circumstances explained in the preface, by the author himself, as follows:

"A paper by the author, being a critical examination into the merits of continuous girders, was prepared six years ago, but its presentation to the American Society of Civil Engineers was delayed till last spring. In this paper the subject for the first time is found to be based without the use of higher calculus on one simple geometrical relation, forming the connecting link between single spans and continuous bridges.

"The same paper, increased with further data resulting from its discussion, is compiled in the short treatise now presented.

"It is hoped that it may contribute to clear opinions as to the real merits of the systems of single and continuous spans, and would lead to a more thorough understanding of the nature of each.

"The subject having never before been treated in this light, it is believed that railroad engineers will not unfavorably receive the results of special studies which have occupied a period of many years, and which in the main are:

"That in addition to the sensitiveness of continuous bridges, the economy claimed for them does not exist theoretically or practically in all instances in which the construction of properly designed compound single span trusses is not limited as to their depths. As a result of these conclusions, there would seem to be one more good reason that the most valuable time of polytechnic students should not be unnecessarily wasted by entering deeply into a theory which more essentially is of mathematical and historical interest."

INFLUENCE OF FIRE ARMS UPON TACTICS. Translated from the German. By Captain E. H. WICKHAM, R. A. London: H. S. King & Co. For sale by D. Van Nostrand. Price $3.75.

This work the author assures us was suggested by the campaign of 1870.

The history of the introduction of fire arms is carefully detailed, and the evolution of modern practice as carefully considered. How modern infantry was brought into use by the previous introduction of cannons; how small arms then completely assumed the lead, and determined both the methods, as well as the forms of fighting, and how for the first time the guns, in the Franco-German war, exercised an influence which may be said to have carried everything before it, owing to the combination of accuracy, range, and complete command of the most varied topography, by extensive use of shells. All this is narrated in a manner which will elicit much attention from outside the circle of military students for whom it is ostensibly prepared.

THE NEW FORMULA OF MEAN VELOCITY OF DISCHARGE OF RIVERS AND CANALS. By W. R. KUTTER. London: E. and F. N. Spon. 1876. For sale by D. Van Nostrand. Price $5.00.

The work of which this is a translation appeared originally as a series of articles in the *Cultur-Ingenieur*, and has been translated by Mr. L. D'A. Jackson, A.I.C.E. It concerns an important branch of hydraulic engineering in which we are in this country considerably behind the time, although, especially in India and in some of our colonial possessions, much has been and more remains to be done in creating and improving means of water transit, both as regards rivers and canals. Notwithstanding this, the velocity formulae now in use are admittedly faulty, and have been set aside on the Continent by the results of more recent experiments. These are substituted in the present work, and they are now presented in an English dress, with several improvements in arrangement and in other respects.—*Iron.*

LECTURES ON MINING. By J. CALLON, Inspector General of Mines. Translated by C. LE NEVE FOSTER and W. GALLOWAY. London: Dulau & Co. For sale by D. Van Nostrand. Price of vol. 1 and Atlas, $13.00.

Of this extensive work, only the first volume is yet complete. The lectures were prepared for the School of Mines at Paris. The author, Mr. Callon, who died some years since, has enjoyed for many years a high reputation for his proficiency in both theoretical and practical science. His connection with the mining schools as a professor, began in 1839 with the Ecoles des Mineurs of Saint Etienne.

Volume First, of his great work, has just appeared. Volume Second has been published in France, but is not yet translated. Volume Third is in course of preparation by a former pupil of the late author.

The contents of volume one are: Definitions and Introduction; Various Examples of Deposits; Prospecting and Explanatory Workings; Boring; Breaking Ground; Machinery for Breaking Ground; Timbering and Walling; Supporting Special forms of Excavations; Excavations in Watery Strata; Laying out, Opening and Working a Mine; Various Methods of Working.

An Appendix is devoted to descriptions of the large Atlas of Plates.

MISCELLANEOUS.

THE entire population of Asia, is larger by about twenty-five millions than the estimate given in last year's issue of Behm and Wagner's work. The increase mainly falls upon the East India Islands and Anam, the figures in the case of the latter being more than double those given in the tables of last year—viz., twenty-one millions. The population of British India is rather less than last year, being 188,093,700, that of British Burmah being about 2,750,000, including tributary or protected States. The whole population of British India is close on 239 millions. In a map of India, which accompanies the work, the varying density of the population in India is shown—from five inhabitants to over 750 per square mile. The greatest density is found, of course, about Calcutta, as also in patches all along the East coast, and over all the North-west provinces. The population of China is given as 405 millions, with 28½ millions of outlying people. Hong-Kong seems to have decreased by upwards of 2,000 since last year, the number now given being 121,985. Japan is set down as 33,299,014. With regard to Africa, the population of Algeria was, in 1875, estimated to be 2,448,961. The population of Egypt shows a slight increase over last year, being now 17,000,000. The inhabitants of Port Said now number 9,650, and of Ismailia 3,779. Many details are given concerning the area and population of the Soudan and Central and West African States, the results of recent explorations. The British possessions in South Africa, show an increase of territory and population, the latter numbering according to the latest data, 1,338,702. According to latest statistics, the whole population of Australia amounts to 1,867,000; of New Zealand to 421,326. In the Fiji Islands the native population seems to be rapidly decreasing. It is calculated now not to exceed 70,000, while the whites, who in 1872 numbered 2,940, were last year only 1,650.—*Engineering.*

NEW STEAM EXCAVATOR.—Messrs Alexander Chaplin & Co., of the Cranstonhill Engine Works, Glasgow, have just constructed a very powerful "steam navvy" or excavator, which they have been exhibiting under steam, in their premises, during the past week. The frame is entirely of malleable iron, with angle irons welded at the corners, plated with 9-16 plates, and weighs 4½ tons. Underneath the frame are two steel axles, each having four wheels, the outside ones double flanged for the purpose of working the machine, and the inside ones single flanged, so as to go on a 4 foot 8½ inch railway guage. The front part of the machine is supplemented by two wings, one on either side, having screws so as to give lateral stability to the machine, when the digger is required to work at right angles to it. The motive power consists of a pair of 8 inch cylinders of the inverted type, with pinion and crank shaft, working into a larger wheel in the barrel, which is grooved to receive the chain. Near the front of the machine is a very strong cast iron column, round which the jib, which is of malleable iron, is made to revolve for one-half of a circle. Two men are required to work the machine, one having entire charge of the engine for hoisting and slewing, and the other man who stands upon a little platform, regulates the out and in motions of the digger. This latter, by the use of a friction clutch and friction brake, has the entire control of pushing the digger out and in to the material to be excavated. Simultaneously with the hoisting or shoving out action, the bucket or spoon is drawn by pitch chain wheels, and it scrapes up the face of the bank, taking a cubic yard of material at every lift. Alongside the machine there must be accommodation rails for the wagons to come and receive the soil; and as soon as the bucket is filled, it is slewed round by the attendant at the engine, either to the one side on the other, right over the empty wagons, and a trigger being drawn, the contents of the bucket fall into the wagon. While the bucket is returning to the working place, it shuts automatically at the bottom, and so is prepared to rake up another fill. The frame is long, broad, and remarkably stable, and by having placed on one end of it the boiler and engines, and at the other the jib, gear and bucket, the whole machine presents the appearance of being admirably balanced, and certain to sit like a rock with an immense strain upon it. The machine is of such a size that it will carry a cutting down to a depth of twenty feet while it is stationed in one level, and it is calculated that by its use the labor of eighty men will be superseded. The one exhibited last week has been built for a limestone quarry near Edinburgh, where it will be employed in tirring off the strata overlying the limestone.

LA COMPAGNIE DU GAZ PARISIEN, previous to constructing some large gasometers near Paris, experimented on the different materials to be used in their construction; among others, on the cement which was to be used for the vertical walls of the reservoirs (*cuves*), with the following results: The cement used was Portland cement of Pouilly in Burgundy. It was found that a brick of pure cement six weeks old, which had been kept in water during that time, broke under a tensile strain of 170 lbs. to the square inch, 12 kilos. per square centimeter; but a brick six months old, which had also been kept under water, broke under a strain of 441 lbs. per square inch, 31 kilos. per square centimeter; that cement hardens more rapidly, when exposed to the sunlight and fresh air, than when affected by humidity; but that this is at the expense of the tenacity and impermeabi ity of the product; hence masonry walls should be sprinkled regularly until the cement has set; that the degree of fineness has an effect on the setting of cement, and consequently upon its ultimate tenacity, for it is a rule that the tenacity is in inverse proportion to the rapidity of the setting; that a mortar made of two parts sand to one of cement broke under a strain of 277 lbs. to the square inch, 19 kilos. per square centimeter, while a mortar of equal parts of sand and cement broke under a strain of 427 lbs. to the square inch, 30 kilos. per square centimeter. The effect of sand upon the shrinkage was shown by the fact that pure cement was defaced by cracks a little more than a foot apart; when mixed with equal parts of sand, the cracks were little more than a yard apart; when three parts of sand to one of cement were used, there were no cracks at all: hence it was this mixture that was used in constructing the reservoirs.

BELLS.—The following list of the reputed weights of some of the most noted bells in the world is taken from the *Mauufacturer and Builder:*—

	Tons.	Cwts.	Qrs.	Lbs.
The Great Bell at Moscow...	198	2	1	0
St. Juan's (also Russian)	80	0	0	0
St. Juan's (also Russian).....	57	1	1	16
The Great Bell at Pekin.....	53	11	1	20
Bell at Nankin..............	22	6	1	20
Bell at Olmutz..............	17	18	0	0
Bell at Vienna, dated 1711...	17	14	0	0
Bell at Notre Dame, Paris, 1680....................	17	0	0	0
Bell at Erfurt (the finest bell-metal extant)............	13	15	0	0
Bell at Montreal............	13	10	0	0
Great Peter, York Minster, 1845....................	10	15	0	0
Great Tom, Oxford	7	11	3	4
Great Tom, Lincoln.........	5	8	0	0
Dunstan, Canterbury........	3	10	0	0

The Montreal bell was cast by the founders of the Great Peter of York, the Great Tom of Lincoln, and the Dunstan of Canterbury.

REDUCTION OF COAL FREIGHTS ON THE TAFF VALE RAILWAY.—The directors of this company have issued a circular announcing a reduction of freight on coal to a considerable extent, so much so that to some freighters it will make a difference of £3,000 to £4,000 a year.

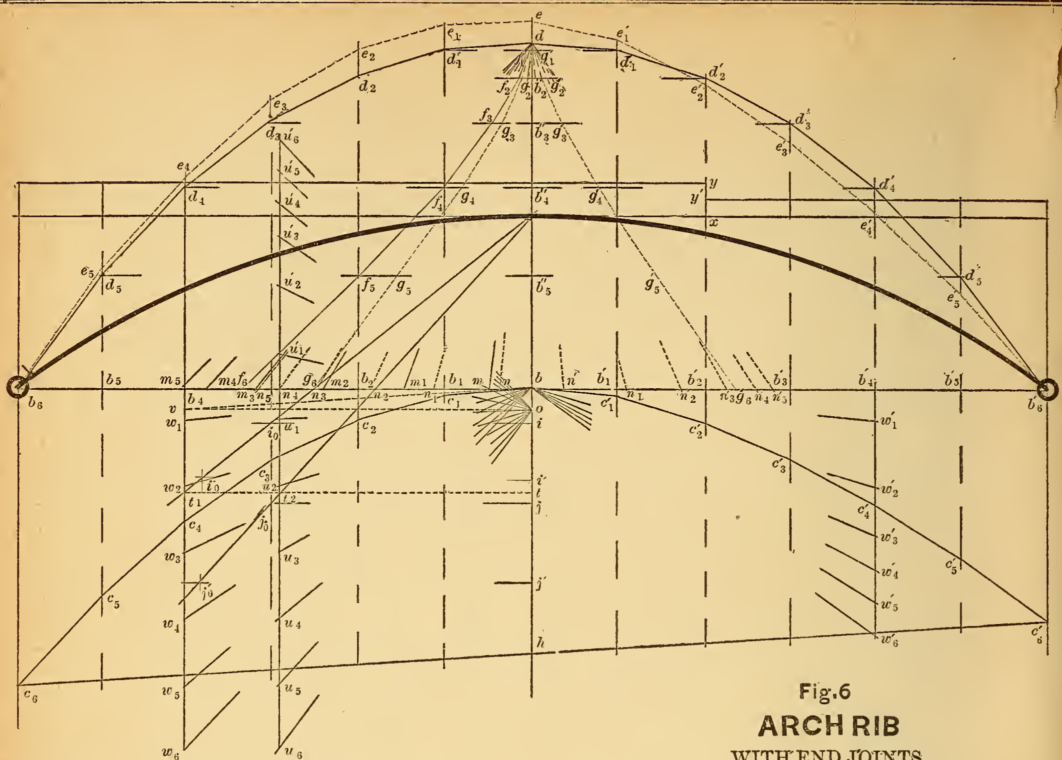

Fig.6
ARCH RIB
WITH END JOINTS.
GRAPHICAL METHOD.

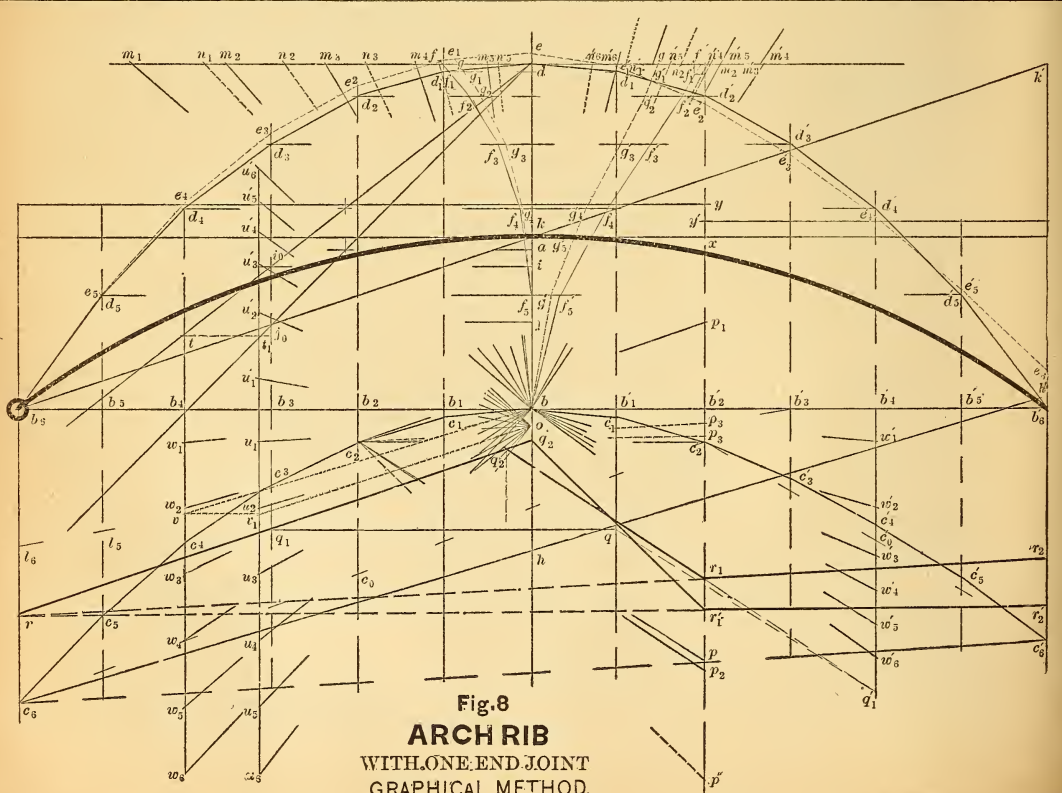

Fig.8
ARCH RIB
WITH ONE END JOINT
GRAPHICAL METHOD.

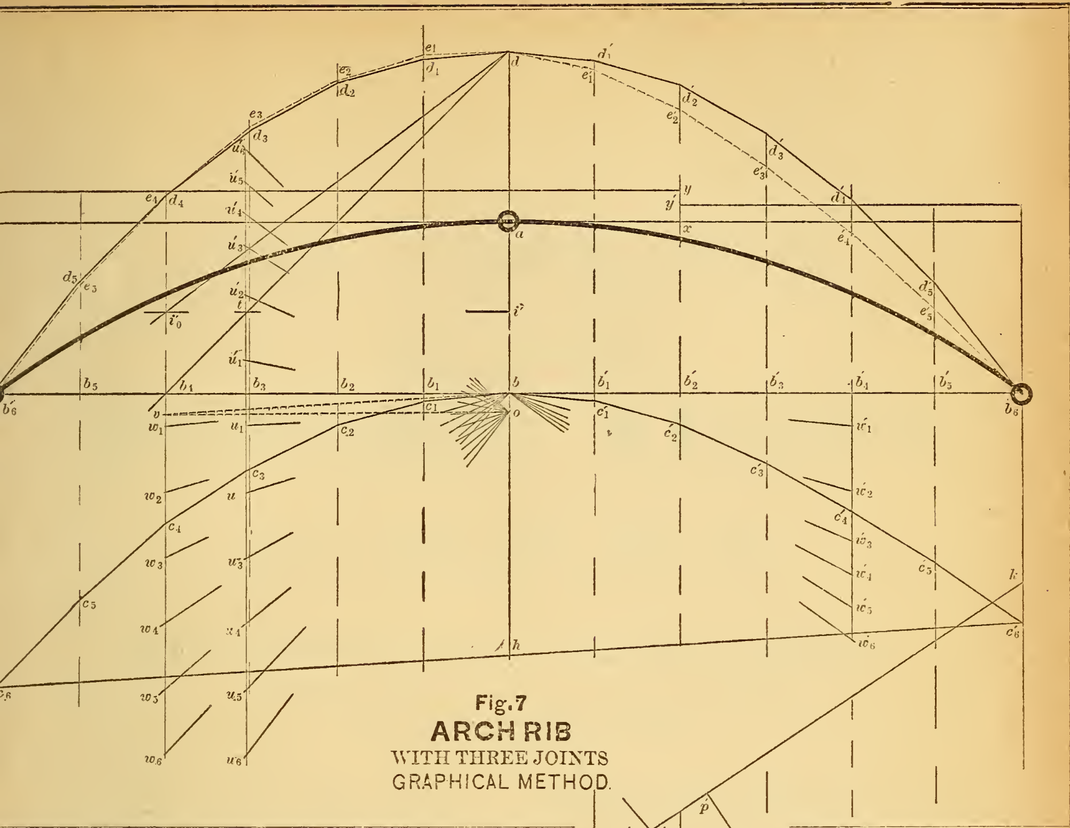

Fig.7

ARCH RIB

WITH THREE JOINTS

GRAPHICAL METHOD.

IX

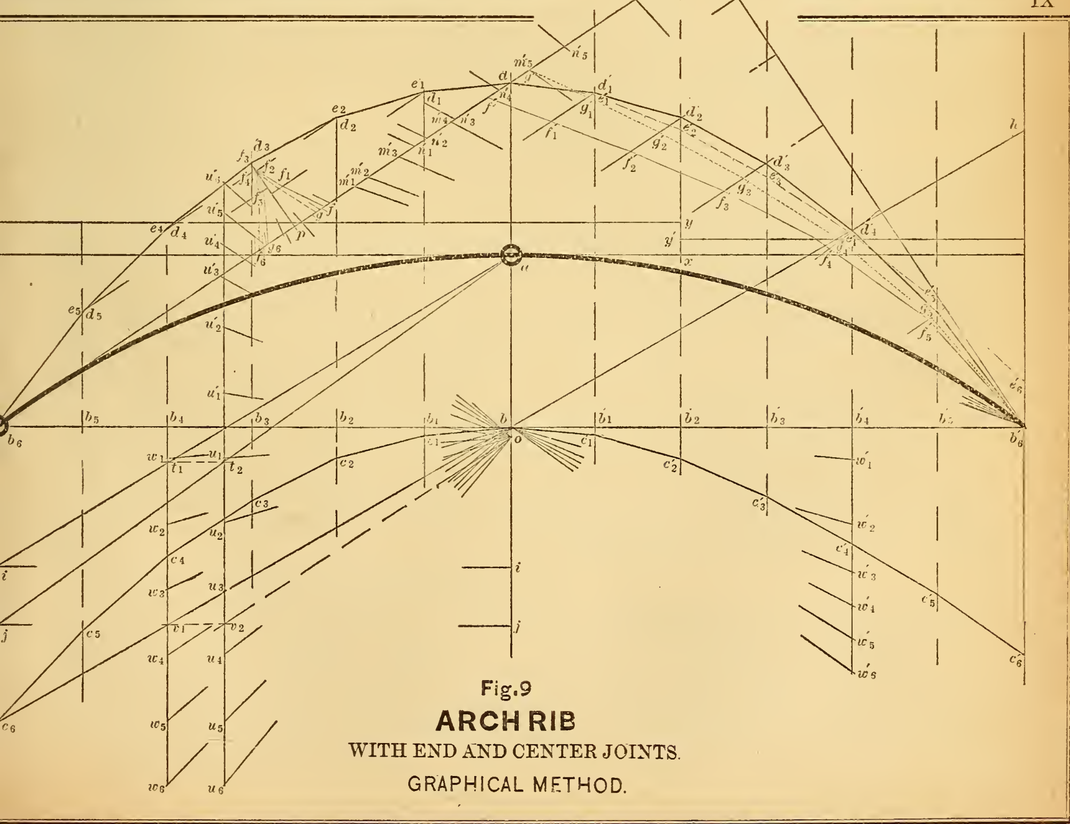

Fig.9

ARCH RIB

WITH END AND CENTER JOINTS.

GRAPHICAL METHOD.

VAN NOSTRAND'S

ECLECTIC

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NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

IV.

ARCH RIB WITH END JOINTS.

Let the curve a of the arch to be treated have a span of six times the rise, as represented in Fig. 6, and having divided the span into twelve equal parts, make the ordinates of the type bd twice the ordinates ab.

Let a uniform load having a depth xy cover the two-thirds of the span at the left, and a uniform load having a depth $xy' = \frac{1}{2}xy$ cover the one-third of the span at the right. Assume any pole distance, as of one-third of the span, and lay off $b_4w_1 = xy$ = one-half of the load supposed to be concentrated at the center; $w_1w_2 = 2\,xy$ = the load concentrated above b_1, etc. Similarly at the left make $b_4'w_1' = xy$ = one-half the load above b; $w_1'w_2' = 2\,xy$ = the load above b_1'; $w_2'w_3' = xy + xy' = \frac{3}{2}xy$ = the load above b_2'; $w_3'w_4' = \frac{1}{2}xy$ = the load above b_3', etc.

From this force polygon draw the equilibrium polygon c, just as in Figs. 2 and 3.

Now the closing line of the equilibrium polygon for a straight girder with ends free to turn, must evidently pass so that the end moments vanish. Hence c_6c_6' is the closing line of the polygon c, and b_6b_6' is the closing line of the polygon d, drawn according to the same law. The remaining condition by which to determine the bending moments is:

$$\Sigma(M_d - M_c)y = 0 \quad \therefore \quad \Sigma(M_dy) = \Sigma(M_cy)$$

which is the equation expressing the condition that the span is invariable, the summation being extended from end to end of the arch.

This summation is effected first as in Figs. 2 and 3, by laying off as loads quantities proportional to the applied moments concentrated at the points of division of the arch, and so find the second equilibrium polygon, or deflection polygon of two upright girders, bent by these moments.

Let us take one-fourth of the ordinates bd as these loads, *i. e.* $bm = \frac{1}{4}$ of $\frac{1}{2}\,bd$; $mm_1 = \frac{1}{4}\,b_1d_1$, etc.: also bn, nn_1, etc., equal to similar fractions of the ordinates of the curve c. Using d as the pole for this load, we obtain the total deflection bf_6 on the left, and the same on the right (not drawn) due to the bending moments M_d.

Similarly g_6g_6' is the total deflection right and left due to the moments M_c.

Now the equation of condition requires that $\frac{1}{2}\,g_6g_6' = bf_6$. That this may occur, the ordinates of the polygon c must be elongated in the ratio of these deflections. To effect this, make $ai = \frac{1}{2} g_6 g_6'$ and $aj = bf_6$, and on the horizontals through i and j at a convenient distance draw the vertical $i_0 j_0$; then the lines ai_0 and aj_0 will effect the required elongation, as previously explained. To obtain the center ordinate be, for example, make $ai' = bh \therefore aj' = be$. To find the new pole o, draw bv parallel to $c_6 c_6'$ and vo horizontal, as before explained.

If ai_0 cuts the load line at t_1 and the horizontal through t_1 cuts aj_0 at t_2, then the vertical through t_2 is the new position of the load line and tt_2 is the new horizontal thrust.

Now using o as the pole of the load line $u_1 u_1'$ etc., through t_2 draw the equilibrium polygon starting from e. It must pass through b_6 and b_6', which tests the accuracy of the construction.

The construction may now be completed just as in Fig. 3, by doubling the pole distance, and finding the tangential thrust along the arch and the normal shear directly across the arch in the segments into which it is divided. The maximum thrust and tangential stress is obtained when the line load covers the entire span.

To compute the effect of changes of temperature and other causes of like nature in producing thrust, shear, bending moment etc., let us put the equation of deflections in the following form:

$$mD_y \cdot \frac{EI}{mn^2n'} = \Sigma\left(\frac{M}{nn'} \cdot \frac{y}{n}\right) \quad \text{(D)}$$

This equation may perhaps put in more intelligible form the processes used in Figs. 4 and 5, and is the equation which should be used as the basis for the discussion of temperature strains in the arch. In equation (D) n is the number by which the rise of the arch must be divided to reduce it to bd, *i.e.*, it is the scale of the vertical ordinates of the type bd, in Fig. 6, so that if bd was on the same scale as the arch itself, n would be unity. Again n' is the scale of force, *i.e.*, the number of tons to the inch; and m is a number introduced for convenience so that any assumed pole distance p may be used for the pole distance of the second equilibrium polygon. In Fig. 6, $p = bd$.

We find m from the equation,

$$p = \frac{EI}{mn^2n'}, \quad \therefore m = \frac{EI}{pn^2n'},$$

from which m may be computed, for EI is a certain known number of foot tons when the cross-section of the rib is given, p is a number of inches assumed in the drawing, n and n' are also assumed. Now D_y is the number of inches by which the span is increased or decreased by the change of temperature, and mD_y is at once laid off on the drawing.

The quantities in equation (D) are so related to each other, that the left-hand member is the product of the pole distance and ordinate of the second equilibrium polygon, while the right-hand member is the bending moment produced by the loading $M \div nn'$, which loading is proportional to $\overline{M}$. The curve f was constructed with this loading, and only needs to have its loads and ordinates elongated in the ratio of bf_6 to $\frac{1}{2} mD_y$ to determine the values of $\overline{M} \div nn'$ at the various points of division of the arch. One-half of the quantities is used, because we need to use but one-half the arch in this computation. Two lines drawn, as in Figs. 4 and 5, effect the required elongation.

The foregoing discussion is on the implied assumption that the horizontal thrust caused by variation of temperature is applied in the closing line bb_6 of the arch, which is so evident from previous discussions as to require no proof here.

The quantity determined by the foregoing process is $\overline{M} \div nn' = q$ say, a certain number of inches. Then $\overline{M} = nn'q$, and $H = My \div n'q \div \frac{y}{n'}$, in which $\frac{y}{n}$ is the length of the ordinate in inches on the drawing at which M is applied.

The determination of the shearing and tangential stress induced by H is found by using H as the diameter of a circle, in which are inscribed triangles, whose sides are respectively parallel and perpendicular to the segments of the arch, precisely as was done in Figs. 4 and 5.

The whole discussion of the arch with end joints may be applied to an unsymmetrical arch with end joints. In that case, it would be necessary to draw a curve f' at the right as well as f at the left, and the two would be unlike, as g and g' are.

This, however, would afford no difficulty either in determining the stresses due to the loads, or to the variations of temperature.

When the live load extends over two-thirds of the span, as in the Fig., the maximum bending moment is nearly in the middle of that live load, and is very approximately the largest which can be induced by a live load of this intensity, while the greatest moment of opposite sign is found near the middle of the unloaded third of the span.

If the curve of the arch were a parabola instead of the segment of a circle, these statements would be exact and not approximate, as may be proved analytically. This matter will be further treated hereafter.

ARCH RIB WITH THREE JOINTS.

Let the joints be at the center and ends of the arch, as seen in Fig. 7. Let the loading and shape of the arch be the same as that used in Fig. 6. Now since the bending moment must vanish at each of the joints, the true equilibrium curve must pass through each of the joints; *i.e.*, every ordinate of the polygon c must be elongated in the ratio of db to bh. To effect this, make $di=bh$, and at a convenient distance on the horizontals through b and i draw the vertical $i_0 b_4$. Then the ratio lines di_0 and db_4 will enable us to elongate as required, or to find the new pole distance ti, diminished in the same ratio, by drawing the horizontal ti through i_0. The new pole o is found in the same manner as in Fig. 6.

Now with the new pole o and the new load line through t, we can draw the polygon e starting at d. It must then pass through b_6 and b_6' which tests the accuracy of the construction.

The maximum thrust, and tangential stress is attained when the live load covers the entire span.

Variations in length due to changes of temperature induce no bending moments in this arch, but there may be slight alteration in the thrust, etc., produced by the slight rising or falling of the crown due to the elongation or shortening of the arch. This is so small a displacement that it is of no importance to compute the stresses due to it. We have for the same reason, in the previous and subsequent constructions, omitted to compute the stresses arising from the displacement which the arch undergoes at various points by reason of its being bent. It would be quite possible to give a complete investigation of these stresses by analogous methods.

The construction above given is applicable to any arch with three joints. The arch need not be symmetrical, and the three joints can be situated at any points of the arch as well as at the points chosen above.

THE ARCH RIB WITH ONE END JOINT.

Let the arch be represented by Fig. 8, in which the load, etc., is the same as in Fig. 6.

The closing line must pass through the joint, for at this joint the bending moment vanishes.

A second condition which must be fulfilled is that the total deflection of a straight girder having one end joint below the tangent at the fixed end vanishes, for the position of the joint is fixed. This is expressed by the equation

$$\Sigma(Mx)=0,$$

in which the summation is extended from end to end.

This condition will enable us to draw the closing line of the polygon c, and also that of d. The problem may be thus stated:—In what direction shall a closing line such as c_6h' be drawn from c_6 so that the moment of the negative triangular area $c_6c_6'h'$ about c_6 shall be equal to the movement of the positive parabolic area c_6bc_6'

To solve this problem, first find the center of gravity of the parabolic area by taking it in parts. The parabolic area $c_6 \angle c_2'$ is a segment of a single parabola whose area is $\frac{2}{3}b_6b_2'\times c_0c_2=\frac{1}{2}h_1 \times b_6b_6'$, when $h_1 +$ the height of an equivalent triangle having the span for its base $\therefore\ h_1=\frac{8}{9}c_0c_2$.

Lay off $l_6b_6=c_0c_2$, and draw l_6b_3' $\therefore$ $b_5l_5=h'$. Lay off $c_2'p_1=h_1$ as proportional to the weight of the parabolic area. Again, $c_2'p$ is proportional to the weight of the triangle $c_6c_2'c_6'$. The parabolic area $c_2'c_6'=\frac{2}{3}c_0'c_4'\times b_2'b_6'=\frac{1}{2}h_2\times b_6b_6'$, as before, $\therefore$ $h_2=\frac{4}{9}c_0'c_4'$, which may be found as h_1 was before.

Let $h_1=pp_2$, then on taking any pole, as c_2, of this weight line, we draw $qq_1 \parallel c_2c_2'$, since the left parabolic area has its center of gravity in the vertical through q_1, and the triangular area in that through q, we draw $qq_1' \parallel c_2p$, to the vertical through q_1', which contains the center of gravity of the right parabolic area. Then $q_1q_2 \parallel c_2p_1$ and $q_1'q_2 \parallel c_2p_2$ give q_2 in the vertical through the center of gravity of the total positive area. The negative area, since it is triangular, has its center of gravity in the vertical through c_2'.

Now if the total positive bending moment be considered to be concentrated at its center of gravity and to act on a straight girder it will assume the shape rq_2r_1 of this second equilibrium polygon, and if a negative moment must be applied such that the deflection vanish, the remainder of the girder must be r_1r_2, a prolongation of rr_1. Now draw $c_2p_0 \parallel rr$, and we have $p_2p_3 = c_6'h'$ the height of the triangle of negative area. Hence c_6h' is the closing line, fulfilling the required conditions.

Again to draw the closing line b_6k' according to the same law, we know that the center of gravity of the polygonal area d is in the center vertical. To find the height p_1p', of an equivalent triangle having a base equal to the span, we may obtain an approximate result, as in Fig. 2, by taking one twelfth of the sum of the ordinates of the type bd, but it is much better to obtain an exact result by applying Simpson's rule which is simplified by the vanishing of the end ordinates. The rule is found to reduce in this case to the following:—The required height is one eighteenth of the sum of the ordinates with even subscripts plus one ninth of the sum of the rest.

Now this positive moment concentrated in the center vertical and a negative moment such as to cause no total deflection in a straight girder, will give as a second equilibrium polygon $rq_2'r_1'r_3'$; and if $cp_3' \parallel rr_1'$, then $p'p_3' = b_6'k'$ is the height of the triangular negative area, and the closing line is b_6k'.

Now the remaining condition is that the span is invariable, which is expressed by the equation

$$\Sigma(M_d - M_c)y = 0, \text{ or } \Sigma(M_d y) = \Sigma(M_c y).$$

Let us construct the deflection curve due to the moments M_d in a manner similar to that employed in Fig. 2. We lay off quantities dm_5, $m_5\, m_4$, etc., equal to one-fourth of the corresponding ordinates of the curve d, and dn_5, n_5n_4, etc., one-fourth of the ordinates of the curve c. We use one-fourth or any other fraction or multiple of both which may be convenient. By using b for a pole we obtain the deflection curves f and f' for the moments proportional to M_d, and the curves g and g' for those proportional to M_c.

Now, Prop. IV. requires that the ordinates of the polygon c should be increased so that gg' shall become equal to ff'. Make $di = gg'$ and $dj = ff'$ and draw as before the ratio lines di_0 and dj_0, then the vertical through t is the new position of the load line.

Find the new length of bh which is ke, and with the new pole o, draw the polygon e starting at e. It must pass through b_6. The new pole o is found thus: draw $bo \parallel hh'$, then v divides the weight line into two parts, which are the vertical resistances of the abutments. From v_1 draw $v_1o \parallel kk'$, then the closing line of the polygon e has the direction kk', a single joint at any point of an unsymmetrical arch can be treated in a similar manner.

A thrust produced by temperature strains will be applied along the closing line kk', and the bending moments induced will be proportional to the ordinates of the polygon d from this closing line. The variation of span must be computed not for the horizontal span, but for the projections of it on the closing line kk'. This construction will be like that previously employed. Another effect will be caused in a line perpendicular to kk'. The variation of span for this construction, is the projection of the total horizontal variation on a line perpendicular to kk', and the bending moments induced by this force applied at b_6, and perpendicular to the closing line, will be proportional to the horizontal distances of the points of division from b_6. As these constructions are readily made, and the shearing and tangential stresses determined from them, it is not thought necessary to give them in detail.

ARCH RIB WITH TWO JOINTS.

Let us take the two joints, one at the center and one at one end as represented in Fig. 9. Let the loading, etc., be as in Fig. 6.

The closing line evidently passes through the two joints, as at them the bending moment vanishes.

The remaining condition to be fulfilled is that the deflection of the right half of the arch in the direction of this line, shall be the same as that of the left half.

Let us then suppose that the straight girder $b_6' p'$ perpendicular to the closing line, is fixed at b_6' and bent first by the moments M_d giving us the deflection curve $b_6' f'$ when b_6' is taken as the pole, and the loads of the type *mm* are one-quarter of the corresponding ordinates of the polygon *d;* and secondly, by the moments M_c giving us the deflection curve $b_6'g'$ when drawn with the same pole, and the loads of the type *nn* also one-quarter of the corresponding ordinates of the polygon *c*. It should be noticed that the points at which these moments are supposed to be concentrated in the girder $b_6' p'$, are on the parallels to kk' through the points d_5, d_6, etc.

Similarly let ff_3 and $f_3 f_6$ be the deflection curves of the straight girder $d_3 p$ (using d_3 as the pole distance), under the applied moments.

We have used now a pole distance differing from that used in the right half of the arch. These pole distances must have the same ratio that the quantity EI has for the two parts of arch. If EI is the same in both parts of the arch the pole distance must be used to obtain the deflection curves in both sides of the middle. In the same manner the curves gg_3 and $g_3 g_6$ are found. Now must the moments M_c causing the total deflection $p' g' - gg_6 = \frac{1}{2}ai$ be elongated so that they shall cause a total deflection $pf' - ff_6 = \frac{1}{2}aj$. The ratio lines ai_0, aj_0' will enable us to find the new position t_2 of the load line to effect this.

To find *o* the new pole, draw through v_2, which divides the load line into parts which are the vertical resistances of the piers, draw $v_2 o \parallel b_6 k$.

Then draw the polygon *e* as in Fig. 7, starting from *d*. It must pass through b_6. We can find also whether Ke_6' has the required ratio to hc_6' by the aid of the ratio lines, which will further test the accuracy of the work.

Any unsymmetrical arch with joints situated differently from the case considered *ed* can be treated by a like method.

The temperature strains should be treated like those in Fig. 8, which are caused by a thrust along the closing line. Those at right angles to this line vanish as the joints allow motion in this direction.

The shearing and tangential stresses can be found as in Fig. 3. Arches with more than three hinge joints are in unstable equilibrium, and can only be used in an inverted position as suspension bridges. These will be treated subsequently. If the joints, however, possess some stiffness so that they are no longer qinge joints, but are block work joints or analogous to such joints we may still construct arches which are stable within certain limits although the number of joints is indefinitely increased. Such are stone or brick arches. These will also be treated subsequently.

A NEW SYSTEM OF SINKING AT THE CANNOCK AND HUNTINGTON COLLIERY.

From the "London Mining Journal."

Those of the public interested in mining enterprises have been aware for some time that a new mode of sinking shafts is about to be tried in England, but the nature of the process to be adopted has not been generally understood. That to which we refer is known as the Kind-Chaudron mode of sinking, being so named from the two eminent engineers who have invented and perfected the process referred to. By this method of sinking a shaft may be sunk through water-bearing strata, and lined throughout with the most perfect iron casing, the whole of the operation being carried on from the surface. At first sight it would appear that such a mode of sinking would be an impossibility, but the fact that some thirty or forty shafts have been successfully sunk on the Continent on this plan places its feasibility beyond a doubt.

The Cannock and Huntington Colliery Company, under a lease from Lord Hatherton, some time since acquired mining rights over about 1,000 acres at Huntington, in the neighborhood of Cannock, and it having been ascertained by boring conducted by the Diamond Rock-Boring Company that known coal measures lay beneath the land in question, it only remained to be determined how the coal should be reached. The boring, which had been carried down to a depth of 218 yards, disclosed the existence of pebble beds and conglomerate at a depth of from fifty to eighty yards, which were not only charged with water at the rate of 250 gallons per minute, but which freely discharged it through the bore-hole, the water rising to a height above the surface of about ten feet in any pipe placed to receive it. Any shaft, therefore, sunk in that ground would have been, in fact, an artesian well, and as the quantity of water which would be discharged through it was in no way ascertainable, the question of sinking was one for most anxious consideration by the directors of the company. They might possibly, by the erection of very powerful engines and pumps, have drained any shaft being sunk during the progress of the works and while the necessary iron lining or tubbing was placed in it, but the circumstances of the case were so exceptional that they felt justified in adopting any process, however novel, by which the enormous expense of sinking in such strata could be avoided.

Messrs. North & Son, of Dudley, the engineers of the company, had introduced to the notice of the directors the Kind-Chaudron method of sinking, and had pointed out fully its peculiar advantages. A visit by the directors to Belgium and France, where pits in progress of excavation were inspected, confirmed the favorable impression which they had formed of this method of sinking, and, after careful consideration, they determined to take the responsibility of adopting the Kind-Chaudron process at Huntington. An arrangement was forthwith made with M. Chaudron to undertake the sinking of two shafts for the company to a depth of about 140 yards each. Special machinery was ordered, foundry and pit-sheds were erected, and what was not long since farming land turned into the busy scene of which we will endeavor to give a slight sketch.

On approaching the colliery the first thing that will strike the visitor is the very high and novel-shaped wooden shed which stands over pit No. 1 (at the other pit No. 2 is being erected). A large foundry shed and a very fine chimney-shaft will also attract attention. The chief interest at present, however, centers in the operations in the pit-shed. To enter this the visitor will have to mount up steps a height of some fifteen or twenty feet above the surface of the ground. Passing through the door at the top he will find himself in what, for want of a better subject for comparison, we may describe as a very lofty barn with a boarded floor. Having arrived here, he will perhaps ask where the shaft is being sunk, for nothing is to be seen of it. In the middle of the floor, however, there is a circular hole of about one foot in diameter, and, if the boring is going on, through this will pass an iron rod, which is suspended by a gigantic screw and chain to the end of an oak beam some ten feet above the floor. A capstan bar through the rod, manned by four laborers, completes all the boring apparatus that is at first sight visible. The end of the beam from time to time slowly rises for about two feet, and suddenly drops again, letting the rod and all that is suspended to it underneath the floor fall with it, the men at the capstan bar walking slowly round as the boring rod rises and falls.

While this monotonous process is going on, the machinery which works the beam and that which rises the tools can be examined. The beam, which projects into the shed from a building joining on to it, and which we may call an annexe, is of oak, and is about twenty-five feet long; its further end is attached to and is drawn down by a piston working in a large cylinder fixed below the beam, and to this steam is admitted at intervals. The beam, therefore, pulled down by the piston at one end and by the weight of the boring apparatus at the other, oscillates under the control of the engineer.

Having examined the beam, we may pass further on into the annexe, and inspect the steam-engine which supplies the power necessary to raise and lower the boring apparatus. The engine is a powerful one, working a train of cog-wheels, the last carrying a drum round which an enormous rope is wound. This rope, it will be seen, passes up a covered way to the pulley at the top of the pit-shed, where it hangs high up overhead ready for use. The time at length arrives for lowering the dredge or basket, and if the visitor will return to the shed he will see this operation. At a signal from the chief borer the motion of the beam is stopped, two baulks of timber are slid up on each side of the boring-rod, and an iron fork or key is laid on them, which just admits through it the passage of the smaller part of the rod, but not of the shoulder of any screw-joint in it; the beam is slightly lowered, and the whole weight of the underground apparatus is borne by the timber we have just spoken of. The chain and screw with the heavy iron swivel at the end of them are detached from the rod of the boring apparatus, and the connection between them and the oscillating beam is severed. The rope now descends from the top of the pit-shed, and being hooked on to the end of the beam lifts it gently up; the men are ready at their posts, and a roller having been slipped under the other end the whole mass of oak to its iron attachments, weighing some five or six tons, is quietly slid back and laid to rest out of the way for a time as gently as if it were a baby being turned over in its cradle. The rope now descends again, is attached to the boring-rods, and in a few seconds the first length is raised above the ground through the hole in the floor we first mentioned; the iron key is again brought into use, while the upper rod is detached and put on one side. The rod in the drill is at length reached, and when this is made fast to the rope the men rapidly remove the floor boards in the middle of the shed, and the observer finds himself standing at the edge of the pit mouth.

On looking down it will be seen that underneath is a circular shaft of some twenty feet in diameter, full of water. The surface of the water is now, perhaps, not more than fifteen feet below the floor of the shed, but when the lower water-bearing strata are reached will, probably, rise some feet higher. The engine now moves again, and the drill is brought into daylight. As soon as it appears the floor boards are replaced, and this part of the apparatus can be approached and examined. When we call the boring tool a drill we do so for want of a better expression, and not that the word properly describes the implement in question. The one now being used at Huntington, which excavates a shaft between six and seven feet in diameter, is the smallest of those that will be used, and yet its weight is about seven tons. It consists of a heavy wrought-iron beam, on the under side of which are several very formidable teeth. Above stands a vertical iron shaft, which may be about fifteen feet long, and on each end of it are attached heavy beams of timber that serve to guide the machine in the hole it has to form in the earth.

The drill is soon swung beneath a carriage, which runs on rails high up in the shed, and is then passed to one side. As rapidly the large dredge is brought over the pit from the other side of the shed, and attached to the rope. This dredge is, in fact, a gigantic iron bucket, made so as to be capable of being easily turned over that its contents may be emptied out of the large window or opening formed in one side of the shed for the purpose. The bottom of the dredge, however, is hinged, and opens upwards in two parts.

The engine is again started, the dredge disappears from sight, the floor is closed, rod after rod is attached and lowered, and when the last rod is fastened the beam is again brought back to its place, and the dredging apparatus moved up and down a few times, being turned round at the same time by the capstan bar. The beam is again detached, and run on one side, the dredge is raised, and when slung underneath its carriage is pushed forward to the window, which is now opened, and by means of a rope and winch gently turned over, discharging its contents of water and mud, broken stones and sand, into a shoot constructed outside the shed. The mud that comes up is, to a great extent, sufficiently liquid to run away down the ditches and over the adjacent grounds, and but little spoil at present has accumulated near to the pit mouth.

We have now described the work as far as it has yet been carried on. The larger drill has yet to be used; this will excavate the pit to the full size of about sixteen feet diameter, but the smaller drill always precedes the larger one, and thus a small shaft is always sunk in advance of the full-sized one, the advantage of this being that the earth loosened by the action of the larger drill always falls into the smaller shaft, by which it can be easily removed by the dredge.

There is no doubt that with continued practice the laborers now employed will work with even greater precision than they do at present in handling the very heavy machines whose motions they have to direct, but with the short discipline they have had it will certainly strike every visitor to the colliery that they work more like artillerymen at heavy gun drill than colliers—every tool seems ready to hand, every man knows his place, the work goes on silently and rapidly, the men working no doubt all the better from being in a dry, well-swept, and well-arranged shed, rather than on a pit bank, where dirt, wet, and cold exhaust their energies and impede their progress. The manufacture of the tubbing, which will be carried on near to the pit mouth, and the mode of sinking it when the boring is completed, must form the subject of another notice. At present we have only described a process which can be seen in operation, and which from its completeness and novelty is certainly one of the most remarkable in South Staffordshire.

CENTRIFUGAL FORCE *v.* UNBALANCED FORCE.

By ROBT. D. NAPIER.

From "Engineering."

At the meeting of the British Association in Glasgow, in September last, Professor Tait gave a lecture on "Force," in which he spoke of "centrifugal force" and "accelerating force" as being "absurdities." Some time afterwards another eminent scientist, writing in a scientific journal, stated that centrifugal force had for years been given up in books of science. If the latter statement were true, then such books for instance, as the late Dr. Rankine's mechanical and engineering works are not books of science, as they define and make use of the term without any hint about the possible phantom nature of the force implied by it; and if Professor Tait is correct, then Sir Isaac Newton held views on this subject which were not only erroneous, but positively absurd; this, to say the least of it, is what most persons would be surprised to learn. It will very generally, I think, be admitted that Newton understood the science of dynamics about as well, and was about as unlikely to use incorrect or inappropriate phraseology with regard to it as any one since his time; and I think on examination, we shall find that "centrifugal force" is neither "an absurdity," nor an erroneous notion, nor an inappropriate phrase.

The general statement that "centrifugal force" has been given up in books of science is not true, but it appears to have been given up in *some* books of science. That being so, and the doctrine that centrifugal force is an imaginary quantity, having to some extent been accepted by thinkers on the subject, it becomes worth while to examine the arguments or evidences on both sides of the question.

In advocating the existence of centrifugal force, one may be placed between the horns of a dilemma of very formidable appearance, and yet one which probably never occurred to the mind of Sir Isaac Newton, or if it did he probably saw his way out of the difficulty so easily that he did not think it worth while to notice it, since he appears to have adopted the idea and the name of centrifugal force without giving any hint about the possible fallacy of the one or the inappropriateness of the other.

The dilemma referred to may be put

in the following form: If there is such a force as centrifugal force, which is equal and opposite to centripetal force when a body is moving in a circle, then the direction of the motion of a body may be altered, while all the forces affecting it balance one another; for, if the body is moving at a uniform rate there can be no forces acting on it, otherwise than at right angles to the direction of motion, and these by supposition balance each other. Again, if variation of the direction of motion of a body may take place while all the forces affecting it are balanced, so also may change of velocity under similar conditions; for change of direction is in reality change of velocity at right angles to the actual direction of motion at any instant. Again if it has to be admitted that *in some cases* the rate or direction of the motion of a body may be altered, while all the forces affecting it are balanced, we cannot stop short of the conclusion that this is always the case, and that in fact the forces affecting any body are always balanced whether its motion is uniform or variable.

The dilemma then resolves itself into this; that either there is no such force as centrifugal force or else there is no such thing in nature as an unbalanced force; one or the other must be given up. At first sight this seems to be almost conclusive against the existence of centrifugal force, but I nevertheless contend that the anti-centrifugalists have cut away the horn of the dilemma that should have been left standing, and are now revolving round the wrong one like flies round a candle, so absorbed by its attractive power that they fail to recognize the counteracting centrifugal force.

On the one hand we must deny the existence of a force of which the effects are as manifest and palpable as those of any other force; or, on the other hand, we must conclude that whether a body is moving at a uniform or variable rate the forces by which it is affected always balance one another.

Before beginning to discuss the main argument against the existence of centrifugal force, I wish to dispose of a so-called argument which to some minds appears to be a very powerful one, though it is based on a complete confusion of the ideas of force and motion.

The argument is that there cannot be any force properly called centrifugal, for if the centripetal force suddenly ceases to act, as for instance by the breaking of a cord which was causing a body to move in a circular path, the body does not fly off radially, but in a tangent to the curve. From the report I have seen of the lecture by Professor Tait, I cannot say that he used this argument in direct terms, but I think part of it cannot bear any other meaning; however that may be, I have seen the argument used by at least one first-class and well-known mathematician and by numerous other persons of smaller calibre. If it had not been for this, I should not have felt justified in taking time to refute so absurd an argument.

In order to show its absurdity it is only necessary to carry it out to its legitimate conclusion thus: the body does not fly off radially, *therefore* there was no outward radial force at the time of the breaking of the cord; the body does fly off tangentially *therefore* there was a tangential force existing; but if the body was moving at a uniform rate there could be no tangential force, for if there had been it must have been either increasing or decreasing the velocity. That the body flies off in a tangent is conclusive evidence that that was its direction of motion at the time the centripetal force ceased to act, but it does not furnish the shadow of evidence as to the forces that were acting the instant before it did so.

To produce velocity both time and force are required, and assuming that centrifugal force exists at all, it is the resistance arising from a body being forced out of a straight line, just as centripetal force is the force pulling it out of a straight line, and the instant the one ceases so does the other, when the body at once moves in a straight line, for the element of time is wanting to allow of radial velocity being produced. The crucial question is, whether an unbalanced force is a possibility. If that question can be answered definitely one way or the other, it must settle the whole matter.

In statics, we know that every force must be opposed by an equal and opposite force, or by forces whose resultant is equivalent to that, at least I presume this will not be disputed. That is to say if A presses against B with a given force, then B will press against A with an equal force. In dynamics, we *assume* that a force may act on a body without being opposed by an equal force, and that the result is motion imparted to the body. I shall endeavor to show by reasoning and examples, that when motion is being produced there is a resisting force which limits the rate at which volocity may be produced by a given accelerating force, and that these two forces are equal. If it be objected that there would be no effect if the resisting force were equal to what may be called the acting force, my reply is that this view of the case overlooks the circumstance that the resisting force arises entirely from the fact that the result is actually taking place.

A very clear illustration of my meaning may be seen in the case of a ship going forwards at a uniform speed. It is manifest that the sum of the forces driving her forwards is exactly equal to the resistance, or the sum of the forces acting in opposition to her motion, and yet she continues to plow her way through the water, for the forces that are opposing her motion exist entirely in virtue of the fact that she is going ahead. If the ship were made fast by a rope while the same force continued to drive her ahead, the strain on the rope would be exactly equal to the forces opposing her motion when she was free to move; but inasmuch as the strain on the rope is not due to the ship going ahead, there is nothing but a statical result.

On the same principle, centrifugal force is the resistance against alteration of the direction of motion, and arises entirely from the fact that the alteration is taking place; and also on the same principle it is equal to the force which is producing the alteration.

We must always bear in mind that we know nothing whatever about force but by its effects, of which the fundamental one is the sensation of pressure, without which it would be as impossible for us to form an idea of force as it would be for a man born blind to form a conception of color. But having by means of sensation acquired an idea of what force is, we can in various ways estimate the relative magnitude of different forces by comparing the effects produced. And whenever we find an effect produced which, according to our experience, force and nothing but force produces, I think we are justified in assuming that a force must have existed to produce the effect. Then, if we can show that resistance against change of velocity produces effects which nothing but force produces, we must come to the conclusion that resistance to change of velocity is a force, and if so, that it is equal to the force producing the change.

Take the following case. If a piece of heavy material, say a piece of lead, weighing 10 lb., is placed in the scale of an accurate spring balance, it will press down the scale till the pointer indicates 10 lb. I think it will not be disputed by Professor Tait, or perhaps any one else, that the pressure exerted by the lead on the scale, is a force downwards on the scale; for if not, what took the scale downwards till the pointer indicated 10 lb.? I do not say that that force *is* the force of gravity of the lead, for the same reason that when a weight is suspended on a chain the force exerted by the first link on the second *is* not the force exerted by the second on the third, but the one is the measure of and arises directly from the other; in like manner the pressure on the scale is the measurement and effect of the gravitating power of the piece of lead, and is all we know about that power.

Suppose now I wish to try experimentally what the effect of rapidly descending will have on the force of gravity, and I take the spring balance and piece of lead and go down a mine with it. When I am descending at full speed I find the pointer indicates exactly 10 lb. as it did before. A little while afterwards I experience a sensation as if I had suddenly grown heavier, and on looking at the spring balance I find that the lead appears now to weigh 12 lb. Of course the explanation is that the rate of descent is rapidly decreasing, and not that the lead had grown heavier. What then is the additional pressure on the scale? Is 10 lb. of the total pressure a force downwards on the scale, and 2 lb. of it not a force? Ten pounds of it is admitted to be a force and not to be the measurement of the force of the force of gravity of the lead, and 2 lb. of it is the measure of—what? Of the resistance which the inertia of the weight opposes to the reduction of its velocity of course; but how can it produce this downward pressure on the scale if it be not a force? On commencing to reascend we get the same result; the force producing velocity upwards is exactly balanced by the resistance to the production of velocity, but the velocity keeps increasing all the same.

I will take one more case, but more apropos to the question of centrifugal force. Suppose a weight to be fitted to the arm of a wheel so that it can slide freely out and in on it, and let it be prevented from flying off the arm by a rim on the wheel; also let a spring be interposed between the weight and the rim. I will further suppose that when the weight is as far from the centre as it can go, the radius to its centre is one foot. If there is no power applied to the wheel the weighted arm will naturally find the lowest point and will press with its own weight, say, 10 lb., on the spring which will press with a force of 10 lb. on the rim. It will be impossible, I think, for any one to deny that the pressure on the rim is a force acting downwards on it, and therefore in a radial or directly outward direction from the centre.

If we now put the wheel in motion and make it run at about 54 revolutions per minute, then each time the weight passes its lowest point, the pressure on the spring and therefore on the rim will be equal to 20 lbs. Will half of that pressure be a force and half of it not a force, or will half of it be a downward force and half of it be an upward force? I see no escape from this absurdity but by admitting the existence of contrifugal force, and the non-existence of unbalanced force.

Let the wheel be placed horizontally, and be driven at the same speed as before; the force exerted on the spring will now be 10 lbs. constantly. Is any one justified in saying that in this case the spring is forcing the weight towards the centre, and deny the right of another to maintain that it forces the rim outwards? This is the ground that the anti centrifugalists take; they would say that the rim presses on the spring, and the spring on the weight forcing it out of a straight line. This is true enough, but the converse is also true, that the resistance being moved out of a straight line produces the pressure on the spring, and makes it press on the rim. It would be possible, however erroneously, to take the former view of the matter to the exclusion of the latter in such a case, as for instance, the moon revolving round the earth, where the centripetal force exists totally irrespective of the motion of the body, and is the originating cause of the curvilinear path. But if we are entitled to think in this manner, we are equally entitled to say, when the force is entirely due to to the motion, that it is entirely centrifugal, and that there is then no centripetal force. Both views are equally wrong, and the only legitimate view seems to me to be the old-fashioned one, that when a body is moving in a circular path, the centrifugal force is equal and opposite to the centripetal force. Take the case of the common ball governor of an engine. If there is no such force as centrifugal force, what makes the balls fly outwards? —the force of gravity is pulling them out of the straight line, but surely the centrifugal force sends them out till gravity equalizes the outward and inward forces.

To me, the statement that a force cannot act without having an equal force to act against, is more like an axiom than a proposition requiring to be proved, for if it were otherwise it seems evident that a force could act on a vacuous space, which is a manifest absurdity. But it may be asked in the case, for instance, of gravity producing motion in a mass, what is the resisting force? Is inertia a force? Certainly not; but it is that quality of a mass which limits the rate at which motion can be imparted to it with a given force; which, in fact, prevents it from acquiring infinite velocity in an instant, and makes it possible to apply force to a body free to move. The resisting force only comes into existence when change of velocity begins to take place, and lasts only as long as change of velocity is taking place, in a similar manner to centrifugal force in relation to change of direction; and also in a similar manner to the case of the resisting forces to the motion of a ship. The latter is a case of uniform motion, and the former of variable motion, but the principle is the same. My contention is, that if we remove the support on which a mass has been resting, we that instant bring another resisting force into play. The one may be called a statical force, and the other a dynamical force, the latter being the result of unbalanced statical forces. We cannot form a conception of this resisting force, but neither can we of the force of gravity, though the latter we consider the most natural thing in the world, just because we have been used to see and feel its effects. From what has been said it will be seen that if centrifugal force has to be given up, then the impact of a cannon-ball on a target is not a force, and the pressure of the exploded powder on the ball in the gun is not a force. These, and the great majority of what we have been accustomed to call forces, must stand or fall with centrifugal force.

THE TREATMENT OF IRON FOR THE PREVENTION OF CORROSION.

By Professor BARFF, M.A.

From "Journal of the Society of Arts."

While experimenting, two or three years ago, with my friend, Mr. Hugh Smith, on different methods for preventing incrustation and corroding of steam-boilers, I was led, through the failure of all the processes employed, to believe that, if it were possible to convert the surfaces of iron plates into the magnetic, or black oxide of iron, in such a manner that the particles of black oxide formed in the position of the original particles of iron could be rendered perfectly adherent to the iron surface, which does not become per-oxidized, and perfectly coherent with one another, the object would be effected. I do not intend to enter into the chemistry of the oxidation of iron to its full extent; it would take too much time, and it would rather tend to confuse than to enlighten those who are not well up in their chemistry, and would raise questions which would bring on prematurely a collision with the views of some of my brother chemists, which collision, under suitable circumstances, at some future time, not very remote, I look forward to with considerable satisfaction, as it will be the means of solving many phenomena which have never yet been explained. A piece of dry iron, its surface being polished, may be exposed for any length of time to dry air without rusting, but it begins to rust at once as soon as the slightest moisture comes in contact with it. We have to consider only two oxides of iron: one containing fifty-six parts by weight of the metal to sixteen parts of oxygen, and the other containing twice fifty-six parts of iron and three times sixteen parts by weight of oxygen. We speak of these oxides as the protoxide and sesquioxide, or as ferrous and ferric oxide.

Immediately the protoxide is formed, it being more moist, it unites with oxygen and becomes gradually converted into the ferric oxide. Now, let us suppose a moist iron plate to come into contact with oxygen. It is clear that the protoxide will be first formed, and this rapidly becomes converted into the higher oxide. Now, suppose you take a solution of the salt of the higher oxide and put into it metallic iron, in time, the air being excluded, this higher salt will become converted into a salt of the lower oxide. Let us now see how this bears upon the rapid oxidation of iron in the presence of moisture. We have seen that when oxygen comes in contact with moisture the first oxide is formed and becomes rapidly oxidized into the higher one. But this higher oxide is in contact with metallic iron, which will reduce it to the lower oxide, thus becoming oxidized by the oxygen which it has taken up from the higher oxide. You will now see clearly how it is that iron rusts throughout its whole substance with such rapidity, for the oxide of iron serves as a carrier for atmospheric oxygen to the iron to almost any depth. There is another oxide of iron, called the black or magnetic oxide, containing three times fifty-six parts by weight of iron, and four times sixteen parts by weight of oxygen. Some chemists consider this oxide to be a sort of mixture of the two others, and they call it ferroso-ferric oxide; whether this be the case or not does not matter to us this evening. But it is a most important point for our consideration, that this oxide undergoes no change whatever in the presence of moisture and atmospheric oxygen. Nor does any temperature to which it can be exposed, in any of the ordinary uses to which iron is applied in the presence of moisture, either decompose it or produce its further oxidation. In every school where chemistry is taught, in the most elementary lecture on hydrogen, the pupils are told that if they pass steam over red-hot iron filings contained in an iron tube, they will be able to collect and burn hydrogen gas at the opposite end of the tube to where the steam enters. For a long time it was thought that the particles of black oxide formed by this decomposition of the steam were pulverulent, and could not be made to cohere into a solid mass. The result of a considerable number of experiments has been to prove that they can be made not only coherent amongst themselves but adherent to the body, and that both these produce a proper formation of this black oxide on the surface of iron plates; for, as I will show you later on, the oxidized surface of the iron resists for a long time, and more effectually, the rubbing with emery paper, than does the simple metallic iron itself, and that there is a very manifest difference between the ease with which a sharp rasp is able to cut away the surface of the iron, and the difficulty with which this black oxide is removed from the surface by that same instrument. The method which long experience has taught us is the best for carrying out this process for the protection of iron articles in common use, is to raise the temperature of those articles, in a suitable chamber, say to 500° F., and then pass the steam from a suitable generator into this chamber, keeping these articles for five, six, or seven hours, as the case may be, at that temperature in an atmosphere of superheated steam. I will presently call your attention to the diagram of the furnace and muffle which I have employed in all our later experiments, and in which all the specimens before you, which will be alluded to in this paper, were prepared. Differences of temperature are employed where different objects are to be obtained. If it be wished to act upon surfaces of polished iron or steel, it is desirable to let the temperature remain at 500° F., until the operation is completed. Articles coated in this way will not resist the action of continued moisture such as has prevailed for the last two months, when exposed out of doors; but they will resist the action of any amount of moisture with which they may come in contact in a house or building; and the reason of this will be very obvious, because only a thin film of the iron, on its surface is transformed into the black oxide. This I will explain more fully to you, when I call your attention to individual specimens. At a temperature of 1,200° F., and under an exposure to superheated steam for six or seven hours, the iron surface becomes so changed that it will stand the action of water for any length of time, even if that water be impregnated with the acid fumes of the laboratory. Before calling your attention to our failures and successes as they lie before you on the table, I will just allude to a few of the uses to which this process may be, as I consider, successfully applied—to water-mains, also to water-connecting pipes, as well as to the water-pipes used inside the house, which, in this case, would supplant their leaden predecessors. In this hall of hygiene, these words will, doubtless, sound as sweet music to the ears of many of those who have honored me with their attendance this evening. The greatest objection to the use of iron pipes for the supply of water in houses hitherto has been this, that by rusting they caused the first quantities of water drawn off in the morning to be dirty and turbid; now this will be entirely prevented, if the pipes be first exposed to the treatment which I have just explained to you—of course gas-pipes could with advantage be similarly acted upon —and as the surface, when oxidized, is harder than the natural surface of the iron, the friction of large bodies of water through the pipes, and the friction necessarily employed in fixing them in their places, would be much better resisted than by the untreated iron itself. I cannot over-estimate the advantages which the employment of this process must confer on architects, who will be by it enabled to employ iron, whether wrought, or cast, much more largely, not only in the decoration, but in the construction of their buildings. Last summer, I was at a very large house in the country, where the entrance portico, some twenty feet high, was being painted and decorated, when one of the large plaster ornaments of the ceiling broke away from its holdings, and would have fallen to the ground except that it was caught by a workman. This ornament weighed not less than twenty-five pounds, and if it had fallen from this height upon the workmen below, it must have killed them. The ornament had been there many years, and was fixed up in the best method possible, it being supported and secured by iron rods. On examination I found that these rods were rusted through completely to the very center. I need not make any comment upon this, since I have been able to introduce you to iron treated in such a way that it will never rust. Of course if the process will answer for architectural ornaments, it will answer for statues, so that iron may be used instead of bronze, which will materially lessen the cost of casting statues, both in the material and in the expense of making the moulds. You well know that when a tinned saucepan is allowed to get dry on the fire and burns, as the servant calls it, that it is rendered useless until it is tinned again. Now, if such a saucepan be treated by the method I recommend it may be allowed to get red-hot without suffering injury, for the protection on its surface is produced at a red heat. We have experimented on some screws, hinges, locks, keys, bolts, with complete success. It has been suggested to me that the iron nipples used in gas-lights would not corrode, and would, therefore, be more useful, if submitted to this action of super-heated steam. Wherever iron is used, railings, street gas-posts, iron safes for keeping documents fire-proof and thief-proof, the framework of filters, tanks, cisterns for domestic and other uses, iron employed in the erection of temporary buildings—which, I flatter myself, if treated by this process, would become permanent buildings—all these, and many other applications of iron to the arts, would immensely gain by being submitted to this oxidizing action. I think I need hardly take up your time by enumerating other applications for the preservation of iron, for it appears to me that they would be commensurate with most of the uses to which iron is applied, save and except those where friction—such as that to which rails and iron wheels are exposed—would necessarily wear away the coating, as they wear away the material itself.

THE SEWAGE QUESTION.

By Mr. C. NORMAN BAZALGETTE.

From "Engineering."

The object of this communication was stated to be two-fold. First, to limit and define the proper application of the various systems introduced from time to time for dealing with the sewage of towns. Secondly, to direct attention to certain subordinate questions arising upon the practical operation of such systems. For the purposes of this paper, the following classification had been adopted : 1 Treatment with chemicals; 2. Application of sewage to land, including irrigation and intermittent downward filtration; 3. The dry-earth system; 4. The Liernur or pneumatic system; and, 5. Seaboard and tidal outfalls.

1. *Treatment with Chemicals.*—In this section of the paper, reference was made in considerable detail to the practical experience of the lime process at Leicester, Tottenham, Blackburn, and Birmingham; the A B C process at Leicester, Leamington, Crossness, Hastings, Southampton, Bolton, and Leeds; the sulphate

of alumina process at Coventry; the phosphate of alumina process at Tottenham, Barking, and Hertford; Goodall's process at Leeds; Bird's process at Cheltenham and Stroud; Dugald Campbell's process at Battersea; and Whitthread's process at Tottenham. It was stated, generally, that the experience of these processes was more or less identical with that which had been derived from Holden's, Hille's, Lenks', Suvern's, Scott's, and in fact all other methods in which, by the admixture of chemicals, it was sought to effect the purification of sewage by the precipitation of the dissolved and suspended impurities, and the ultimate realization of the precipitate in the form of a manure. This experience, coupled with certain opinions of Professor Frankland, Mr. Krepp, and Dr. Corfield which were cited, was relied upon as establishing the following conclusions: That no chemical process could efficiently deal single-handed with sewage, but must be assisted by subsequent natural or artificial filtration of the treated sewage, and therefore no chemical process *per se* should be adopted for the purification of town sewage. The principal objections to chemical processes, which appeared upon the experience of the places where they had been adopted, and upon which this conclusion was founded were, inefficiency of treatment, cost of treatment, and difficulty of manipulating the accumulations of sewage sludge.

2. *Application of Sewage to Land.*—The author first considered whether sewage could be made to yield an agricultural profit. The Parliamentary return of 1873 was referred to, and the financial position of the Warwick farm was specifically examined. The question was also raised, whether sewage possessed any fertilizing value beyond ordinary water for the purposes of irrigation, and the experience of the Barking farm having been appealed to upon this point, the conclusion was laid down, that no profit ought to be expected from the cultivation of crops by sewage irrigation. The next point discussed was whether any definite standard could be laid down as to the proportion population should bear to acreage in the practice of irrigation, the proportions exhibited by eleven towns being referred to, and it was determined that it was impossible to frame a specific rule. The theory of intermittent downward filtration was then investigated, as based upon the laboratory experiments of the Rivers Pollution Commissioners; and it was argued that the proportions which they had affirmed population might bear to acreage, ranging in the case of one acre drained six feet deep from 2000 to 3300 persons to the acre, were too high, and were not justified by the experiments. The practice of downward filtration at Merthyr was next referred to, and it was shown that the extent of its practical operation there had been exaggerated, and that the results confuted instead of confirmed the proportions of the Rivers Pollution Commissioners. The experience of Walton and of Kendal was also reviewed, and the following general conclusion completed this section of the paper: That where land could be acquired at a reasonable rate, irrigation was the best and most satisfactory known system for the disposal of sewage, but that intermittent downward filtration might be practised where the necessary surface area for broad irrigation could not be obtained. Experience, however, showed that the permanent proportion of population to acreage, where land was drained six feet deep, should in no case exceed 500 or 600 persons to an acre.

3. *The Dry-Earth System.*—The applicability of this system to towns was next considered, and it was shown that it must be supplementary to, and not substitutive of, a water-carriage system, thus enormously increasing the cost of making sanitary provisions for towns. The effect of its introduction into the metropolis, as a test case, was illustrated by figures, to prove that it would be superfluous, costly, cumbrous, and impracticable. Indeed, its applicability became diminished in the inverse ratio to the increase of population, to which it was proposed to apply it; and though it might be occasionally used with advantage in hamlets or detached buildings and institutions, it was unsuitable for the wants of towns.

4. *The Liernur or Pneumatic System.*—A description of the mechanical characteristics of this system was first given, and then the experience yielded by its operation at Leyden, Amsterdam, and

Dordrecht, was specifically analyzed. It was suplementary to, and not substitutive of, a water-carriage system, extremely costly, and its mechanism was complicated and liable to get out of order. The accumulation of sewage residuum in the central reservoir, and its subsequent decanting into barrels, were operations which could not fail to be objectionable and offensive. Its appliances were therefore not suitable for a high-class community, and no return from the manufacture of "poudrette" could be expected. In conclusion, it was urged that the system was of such a character that, though it might have a partial province in the tide-locked cities of the Hague, where no system of sewerage was available, it should never be imported into an English town.

5. *Seaboard and Tidal Outfalls.*—The first point considered was the return of the sewage of seaboard towns upon the beach; and it was maintained that where care had been taken to determine by float observations the force and set of the currents to which the sewage was to be committed, there was no difficulty in preventing such a result. The sea constituted the most natural and economical outfall for the sewage of towns situated upon it, and such means of outfall should be adopted. With regard to sewage outfalls upon the tidal portions and estuaries of rivers, there ought to be, arguing from the experience of the metropolitan outfalls, and assuming that proper precautions were taken in the selection of the outfall, and the exclusion of silt from the sewers, no danger of the silting up of the navigable channel.

THE GRAM MAGNETO-ELECTRIC MACHINE.—M. Tresca has made a careful measurement of the power required to drive a large and a small gram machine and compared the result with the light generator. A photometer disk was used, of which one portion was illuminated only by the electric light and an adjacent portion only by a carcel burner consuming forty grams of oil per hour. Much trouble was experienced from the difference in color of the two lights, and the equality was best obtained by interposing two plates of glass, one of light green and the other of light pink. Owing to irregularities in the carbons the light continually underwent irregularities sensible only to the photometer. The light of the larger machine was placed forty meters from the disk and the burner moved until the square of their distance should be as 1850:1, which was about the mean ratio of the two lights. When the two portions of the disk appeared equally bright the observer gave a signal and instantly the power and velocity were observed. The larger machine had a length of 80 centimeters, width 55 centimeters, and height 58.5 centimerers. The average number of turns per minute was 1274, and the work 576 kilogrammeters or 7.68 horse-power. The light being 1850 burners, would equal .415 of a horse-power per hundred burners, or .31 kilogrammes per burner.

The smaller machine had a length of 65 centimeters, breadth of 41 centimeters, and height of 50.6 centimeters. It made 872 turns per minute, and gave a light of 302.4 burners. This required 211 kilogrammes, or 2.8 horse-power, equivalent to .92 of a horse-power per hundred burners, or .69 kilogrammes per burner.

The consumption of oil to produce a light equal to that of the larger machine would be about 71 kilogrammes per hour or 194 cubic meters of gas. The cost of the oil would be therefore in Paris about a hundred times that of the electric light, or that of gas fifty times, to produce the same light. The comparison with the smaller machine would be less favorable. The carbons for the larger light had a cross-section of eighty-one millimeters, and the ordinary consumption was a little over a centimeter in length per hour.

—*Comptus Rendus.*

MAGNETIC SEPARATOR.—We have alluded in former reports to several machines employed in separating iron from copper filings and in concentrating the magnetic sands in Canada and elsewhere. We now learn that the machine invented by M. Charles Vavin is employed in concentrating the iron sands of the Island of Reunion, the pure magnetic particles being separated on the large scale and exported as iron ore to France.

IMPROVEMENTS IN THE MANUFACTURE OF POWDER.

Translated from "Revue Industrielle."

The manufacture of explosive substances employed in the various industries, has within a few years made considerable progress. The most important improvement is certainly that of Dynamite, the invention of M. Nobel. This chemist in finding a simple method of depriving nitro-glycerine of its more dangerous qualities, at the same time preserving its high explosive power, has opened to inventors a new method, and suggested the creation of a series of products in which nitro-glycerine enters in greater or less proportion.

It will be sufficient to cite among others Hercules powder, in which nitro-glycerine is associated with the elements of ordinary powder, or with potassic chlorate; Ohlsen's and Norbin's powder, in which it is united with ammonic nitrate and wood charcoal; the varieties of lithofractors of which nitro-glycerine is the active principle; dualine in which a union is attempted of pyroxiline, nitre, nitro-glycerine, etc.

Notwithstanding the improvements in the preparation of dynamite, its manufacture must still be considered quite dangerous, and it requires moreover the employment of substances comparatively expensive, such as glycerine free from lime; concentrated nitric acid etc., all of which contribute to raise its price considerably above that of common powder.

Although much to be preferred in extensive works, where it can be brought to bear upon the harder rocks in water-bearing or submarine strata, dynamite loses a portion of its economical advantage when in the presence of rocks of medium hardness, where the properties of common powder permits the latter to be used with success. A preference for common powder is also explained by the disinclination of the workmen to adopt any innovation, even the best, and by the bad reputation caused by late accidents, although chargeable only to carelessness of miners.

M. Nobel has perfectly comprehended that notwithstanding the excellence of dynamite, it would have to contend against prejudices and established customs. So in 1870 he patented the employment of explosive compounds, consisting largely of nitrates, and differing from powder in the introduction of a certain quantity of nitro-glycerine.

When any powdered nitrate, such as nitrate of potassium, of sodium, of barium or of lead, is intimately mixed with carbon or any substance containing carbon or a hydrocarbon, such as resin, sugar, amidon, there results a mixture which if hermetically closed in by strong resistances, burns too quietly to be considered an explosive compound. But a small addition of nitro glycerine intimately mixed with such a preparation, in such manner as to form a layer upon the separate grains, will induce an instantaneous combustion throughout the mass and the consequent development of intense heat.

Considering the nature of such a mixture, it is evident that the proportions of the several ingredients may be largely varied without other effect than to increase or diminish the explosive power.

M. Nobel gives the composition of mixtures which serve as types of those of great strength and presenting the greatest security:

	1st type	2d type
Barium Nitrate........	68	70
Charcoal...............	12	10
Nitro-glycerine.........	20	20

The addition of five to eight parts of sulphur to either of these mixtures augments slightly the power but diminishes the security.

Among the objections urged against dynamite, the most serious and the best founded relates to the exudation of nitro-glycerine from the grains saturated with it, and its gathering into little drops of which the least shock determines the explosion.

In 1873 M. Nobel secured a new patent designed to avoid this grave inconvenience. There were already a number of patents for explosive compounds made by mixtnres of nitrates of sodium, potassium, barium, ammonium, lead etc. carbonaceous matters, bituminous coals, or hydrocarbons; nitro-glycerine.

M. Nobel knew that in mixing a hygroscopic nitrate (sodium or ammonium nitrate) with any carbonaceous matter such as resin, sugar, or amidon, and with nitro-glycerine, if the compound were exposed to a humid atmosphere it would soon absorb water in which the nitrates would be dissolved, and thus exuding would cause the nitro-glycerine to exude also. But if all or a part of the carbonaceous matter is replaced by paraffine, ozokerite, stearine, napthaline, or any other fat substance which is solid at ordinary temperatures, and which will make an intimate mixture with the nitrates when reduced to fine powder, each grain of hygroscopic nitrate will become covered with a layer of the fatty substance, which will protect it from the action of the humid atmosphere. Furthermore the presence of paraffine or an analogous body prevents the exudation of nitro-glycerine even under the prolonged action of water.

It would be useless to attempt to give the composition of the numerous explosives, and two formulas only are therefore given, and which may serve as types:

Sodic Nitrate	69
Paraffine	7
Carbon	4
Nitro-glycerine	20
	100

Ammonic Nitrate	75
Paraffine	4
Carbon	3
Nitro-glycerine	18
	100

The patent specifies the employment of any substance greasy or glutenous to act in the double capacity of preventing the action of humidity upon the nitrates, and the exudation of the nitro-glycerine.

It has been deemed necessary to present the foregoing facts, before proceeding to explain the improvements covered by a patent of M. Courteille. His invention consists: 1st, in a modified form of blasting powder; and 2d, in a process of manufacture which we will briefly describe.

The principle of the invention consists in combining the ordinary elements of powder in the course of manufacture with the constituents of nitro-glycerine, in such manner that at the completion of the process there shall result a relatively large amount of powder holding a small amount of nitro-glycerine, completely absorbed and rendered stable by the materials of the powder.

The essential property of this compound is that it combines the properties of powder and of nitro-glycerine; not being capable of explosion in the open air, neither by friction nor percussion; only when enclosed and under pressure.

In its manufacture, the elements of both these explosives are brought together. First the nitrates of sodium or potassium or a mixture of them; sulphur, carbon in any convenient form, such as peat, coal, wood, charcoal or lignite. Then added to these constituents are the elements of nitro-glycerine, sulphuric acid, nitric acid, and oils or resin, such as paraffine, coal-tar etc.

The proportion of nitro-glycerine or nitro-resine is to be varied according to the quality desired in the explosive; to be increased when a destructive effect is to be produced, and diminished if only a displacement of material is desired.

The best method of preparation is the following:

Take fourteen to twenty parts of peat absolutely dry, and mix with three to five parts of oil or resin; add then from three to fifteen parts of acid mixture (two parts sulphuric to one part nitric); then mix eight or ten parts flowers of sulphur, with sixty or seventy parts of a hydrated solution of potassium or sodium nitrates or a mixture of the two. Put the whole mass in a steam-drying apparatus and stir vigorously for an hour, keeping the temperature between 101° and 110° C. Then gradually lower the temperature to 65° to complete the drying process. A small amount of remaining moisture produces the best results.

The inventor recommends for a mixer a well-known contrivance, consisting of a solid spindle working through a hollow one, each furnished with wooden arms, and made to turn in opposite directions. He also recommends that the temperature during trituration be maintained between 101° and 110° C, as it is manifestly important to keep the heat above the boiling point of water, and below the melting point of sulphur.

The acids of the mixture should be in

excess of the resinous and oily matters employed, so that none of the latter be left unaltered in the final product.

The advantages of this powder are; —its explosive force, which is from three to five times as great as that of common powder; the safety of its manufacture and use; and finally its excellent action. It costs much less to make than common powder, and the addition of the nitro-glycerine is effected without endangering life and property.

ON THE SYSTEMS OF CONSTANT AND INTERMITTENT WATER SUPPLY, AND THE PREVENTION OF WASTE.

By GEORGE FREDERICK DEACON, M. Inst. C. E.

Minutes of Proceedings of the Institution of Civil Engineers.

It has always been the custom to regard modern systems of drainage and water supply as great sanitary benefits; and if the state of things which they have induced be considered simply in relation to that which, without them, would exist in a densely-peopled district, the estimate is correct. But in the search for personal comfort in matters of household arrangement, the system of mere external drainage and water supply, for ages thought sufficient, was changed to one in which arterial connections were introduced between the dwellings of hundreds of thousands of people.

The altered arrangement had its obvious benefits, but, like almost every change in the manner of applying any scientific principle, or in the details of an invention, it developed new defects, which were either not noticed, or, if regarded at all, were treated as comparatively unimportant. These defects, however, are by no means necessarily inherent in the altered system, but are a consequence of the utter thoughtlessness with which the details in connection with dwelling-houses have in many instances been carried out. It is useless to inquire whether those who so readily caught at the idea of bringing drains and water pipes into more convenient places, ever contemplated the magnitude of the evil, which on the introduction of such new channels for the spread of epidemic disease, would become possible. Certain it is, that if any had the knowledge of the results which might ensue they were powerless to ensure throughout the country the exercise of those precautions which could alone render the system safe. The public drainage and water supply may generally have been executed under the best advice of the day; but, owing partly to the want of parliamentary powers, partly to the difficulty of supervizing in detail the work of speculative builders, partly to the fact that the control of the engineer was no longer thought necessary when the doors of dwelling-houses were reached, and partly to an abuse of the feeling that every Englishman's house is his castle—the strange incongruity has arisen, of works intimately affecting personal health and comfort, devised in a manner so crude, and indicating so little thought and intelligent action, that, when contrasted with the comparative perfection of those arrangements which might at a trifling extra cost have been adopted, the anomaly appears almost unaccountable.

Unexceptionable house drainage, however seldom realized, is generally regarded as indispensable; but the necessity for preventing waste of water is far less obvious. The consumer recognises in such prevention no direct sanitary benefit, and so takes little pains that the water fittings shall be of the best possible construction, and the pipes of the required strength; and although on the part of those who supply the water great alarm is often manifested, the conditions required to prevent leakage, even when no substantial impediment to its prevention exists, are often entirely disregarded. It might be supposed that water companies would be so influenced by the risk of increased future expenditure, that they at least would resort to all practicable means for the prevention of waste; but, at the present time, many of those companies are allowing water to be laid on at high pressure for the supply of service pipes and fittings such as must inevitably, in the course of a few years, lead to great and continuous waste; and if this obtains under the control of bodies whose pecuniary interests are so intimately affected, it is easy to understand that the laxity in the case of many water committees of corporations and local boards is equally great.

When conditions such as these prevail, it is not strange that the state of preexisting fittings and pipes is almost wholly neglected. There are but few towns, except those in which a water supply has only recently been introduced into the houses, which do not present the most incongruous combination of pipes and fittings of every kind in use since, or even before, the abandonment of those hollow trunks of trees which formed some of the earliest water mains, and many miles of which have recently been dug up. Between such antiquated appliances, and the pipes of the great strength and fittings of the comparatively perfect mechanism now known to be necessary to resist the influence of frost, surface traffic, and increased internal pressure, the step is a wide one; even the very existence of many pipes is often unknown. It is not surprising therefore that under both roads and houses there are innumerable sources of continuous waste, which no ordinary inspection, however careful, can detect. Exhaustive reports have been prepared by engineers; Parliamentary Committees and the Board of trade have inquired into the subject in the most thorough manner, and in a few towns complete success has attended the endeavors to prevent waste; but all this has done little to relieve the feeling of comparative helplessness which so generally prevails.

Under these circumstances the Author submits the following remarks on the subject generally, together with the results of his experience in the matter, gained in connection, not indeed with the metropolis, but with a town of the first importance, the water supply of which, having been changed from constant to intermittent service, has been regarded as a most unfortunate example of the evils resulting from waste of water.

2. SOURCES OF WASTE, AND EFFECT OF INTERMITTENT SERVICE ON THE SUPPLY.

The waste of water may be divided into two classes :

1st. Continuous or hidden waste, being that which flows from pipes and cisterns below ground, and sometimes by hidden pipes from cisterns above ground.

2nd. Discontinuous or superficial waste, being that which arises from defective fittings above ground, or from taps and valves temporarily left open.

In addition to these sources of waste there is frequently a considerable loss of water in its application to useful purposes; but as any attempt to induce a spirit of parsimony in this respect is reprehensible, it would be an error to treat the loss thus occasioned as one for the prevention of which it is desirable to adopt active measures. The expression, "water used or consumed," will therefore, in this Paper, include such as is drawn off by hand, whether actually applied to useful purposes or not.

Out of every 100 gallons of water passing into a service main during twenty-four hours, it is not unusual for 35 gallons to be lost by continuous or hidden waste, and 35 by discontinuous or superficial waste, while only 30 are drawn off for use.

This being the mode of disposition of the water under constant service, it is obvious that, if the duration of supply to the main in question were reduced to twelve hours a day, half the water hitherto wasted, or in this instance 35 gallons out of every 100, would be saved, less the waste from fittings connected with cisterns, which would continue until the storage was exhausted. But this would not be a correct measure of the gross reduction in the volume of water taken, as experience shows that the consumers would, while the water remained on, draw more freely than before, and would generally store as much of it as possible until the supply valve was again opened.

Thus the system of intermittent supply increases to some extent the use, or rather misuse, of water, reducing at the same time the most important element of waste nearly in direct proportion to the reduction in the hours of supply, and as it is the most obvious method by which the loss of water may be limited, the expedient has frequently been resorted to.

3. OBJECTIONS ON SANITARY GROUNDS TO INTERMITTENT SUPPLY AND WASTE OF WATER.

When water is cut off from a district, the mains and pipes discharge themselves chiefly through leaks at low levels. Air rushes in from defects at higher levels to fill the space lately occupied by the water, or, if an opening to a pipe happens to be beneath a liquid, that liquid is forced into the mains by atmospheric pressure.

In most towns defects of this nature are probably as numerous and important as in Liverpool, where open ends and large holes in water pipes have been found in direct communication with the sewers and drains, and in such relation to the system of mains and pipes that an indraft of sewer air must inevitably have taken place each day during intermittent service, with which air the water first drawn in the morning must have been charged.

In the poorer districts of many towns water is laid on to closets by pipes direct from the mains. Under intermittent supply the basin cannot, therefore, be flushed out except while the water is on. The more frequent stoppage of the drains follows of necessity, and the pan often remains charged in consequence. The supply pipes are in many instances commanded only by common cocks, which are liable to be left open, and in such cases there must be an indraft from the closet pan each time the water is cut off from the district. These evils, which any person interested in the details of the distribution of water may ascertain, deserve the gravest consideration.

The system of compelling the poorest classes in overcrowded and unhealthy dwellings to store water for fifteen or twenty hours out of the twenty-four—as is frequently the case—in such inadequate vessels as they may be able to provide is also an evident sanitary evil, and is, in the Author's judgment, a most fertile element in the production of intemperance. The storage of water in cisterns for drinking and culinary purposes is most objectionable, much more so than is generally understood. Such cisterns are commonly found in close contiguity to, or even connected by a pipe with, the drainage system of the house. They are often uncovered, and so become the receptacles for decaying animal matter; frequently, too, they are exposed to the direct rays of the sun, and become polluted with organic growth; while, when containing water from some sources, they are often the cause of lead poisoning. The Author has in numerous instances found the overflow pipes from covered cisterns for storing drinking water actually connected with the soil pipes below the traps, so that the surface of the water was in direct contact with air from the house drains and sewers.

Under the intermittent system water for drinking is necessarily subject more or less to these conditions: under the constant system it may be drawn direct from the main, and the cistern may be retained for other purposes.

But, apart from all considerations of the intermittent service which it so often induces, the waste of water is harmful in itself; although some influential men advocate a supply of water so abundant that it may be wasted to an unlimited extent, on the plea that it flushes the sewers and teaches people to be cleanly. But these impressions are not borne out by the facts. Of all the water wasted a large portion does not find its way direct to the drains. Throughout the older parts of Liverpool, for example, even during a dry summer season, and although the basement of every house had been drained, the cellars and the soil around were in most cases completely saturated with water from the town supply. This was their state under intermittent service, and if constant service had been a possibility without a reduction of waste, its blessings would have been greatly alloyed by the augmentation of a condition which could not fail to exercise a prejudicial influence on the comfort and health of the people.

In isolated instances, and for a short space of time, some individual drain may be benefitted by the excess of water; but by the larger portion of the waste, viz., that which finds its way through the ground, and thence through the brickwork, injury is done to the structural condition of the sewers, and to their effective action.

The most enthusiastic advocate of superabundant supplies would scarcely suggest that a larger quantity than 100 gallons per head per day should be given; but assume that 100 gallons per head per day, in excess of the water used, flow continuously down a single house drain. Suppose there are ten inmates, a number far above the average for each house, there will be wasted in twenty-four hours 1,000 gallons, a quantity which could not have the smallest beneficial influence upon any drain. It would be a mere dribble, such as would pass from a pipe, under ordinary pressures, through a hole the size of a pin's head.

The main sewers and outfalls in the lower parts of towns, where the quantity of water is usually too great, receive the aggregated driblets, and moreover, as in those parts the pressure in the mains is greatest, they receive the larger portion direct, and not after passing through the branch sewers above, to which they might in isolated cases be of some benefit.

Happily the cleanliness of branch sewers and drains is not dependent upon the waste of water. It is the result of experience that the sudden discharge of 2 gallons of water through a soil drain each time that drain is made use of is thoroughly effective in cleaning it, and this sudden flush is provided for by all properly drawn-up regulations as to water fittings. Further, at the heads of all branch sewers in towns flushing chambers for intermittent action may be constructed which will give a perfectly satisfactory result with an expenditure of water no greater than 1 quart per head per day.

The advocates for carelessness in the distribution of water may find numerous examples of the disastrous influence of too strong a feeling of security in abundant supplies. That such supplies are desirable cannot be doubted, but it is equally true that they should be conserved with the greatest care for the reduction of rates, the cheapening of manufactures, the systematic and intermittent purifying of sewers and streets, and last, but not least, to provide ever-flowing fountains among the dwellings of the poor.

4. PARLIAMENTARY POWERS GENERALLY FOUND NECESSARY TO PREVENT WASTE.

Now although intermittent supply is the easiest method of limiting the waste of water, it would probably have been seldom resorted to had not the authorities believed that they were powerless to contend by any other means with the growing waste. Nor has an examination of the methods adopted in those towns which have been most successful in preventing waste, often done more than suggest a remedy which has generally been regarded, by the representatives of the ratepayers at least, as worse than the disease. To the reports made by Dr. Pole, M. Inst. C. E., to the Board of Trade and Home Office in 1870 and 1871 on the constant service system, the Author is indebted for much of the following information concerning the change from intermittent to constant supply in two of the towns in which that change has been successfully carried out.

In 1850 the Norwich Waterworks Company obtained an Act incorporating the Waterworks Clauses Act, 1847, which bound them to give a constant supply. When, in 1851, this condition was complied with, and the pressure of water increased to that due to the height of the new reservoirs, the old mains gave way to such an extent as ultimately to necessitate their entire renewal.

In this manner it is probable that the waste was almost wholly confined to the private pipes and fittings, but the means which the Company possessed to control that waste were limited by sections in the Waterworks Clauses Act, which gave power to enter premises between 9 A.M. and 4 P.M., to ascertain if there were any waste or misuse of water; also power to impose a fine not exceeding £5 for any wilful act whereby the water might be wasted.

Such precautions as these clauses rendered possible were taken by the Company; but in Norwich, as everywhere, they proved almost abortive; and about the year 1859, the expenditure of water being 40 gallons per head per day, the Company were compelled to revert to intermittent service.

In the same year, acting under the advice of Mr. Hawksley, Past-President Inst. C.E., the Company obtained an Act to enable them to prescribe the nature in detail of all fittings and pipes and the work in connection therewith, and to interdict the use of any existing fittings and pipes which in their judgment might tend to waste.

The consumers had now no option but to abide by such regulations as the Company chose to make with reference to the fittings and pipes, and in a few years the consumption of water was reduced from forty gallons to about fifteen gallons per head per day, while constant service was restored. It must, however, be borne in mind that these results were obtained, first, by the renewal of the public mains, and, secondly, by the exercise of the almost unlimited powers vested in the Company.

In Manchester, the Corporation, having adopted the Waterworks Clauses Act, and received for the first time in 1851 an abundant supply of water from new works, gave a constant service, and were enabled to continue it. As in the instance of Norwich, however, the repression of waste was attempted under the Waterworks Clauses Act, 1847, and failed. In 1858 the Corporation, therefore, obtained an Act empowering them to refuse to supply water to any apparatus not so constructed as to prevent waste. But, inasmuch as no authority was named in the Act to settle the repeated disputes as to whether the fittings were so constructed as to prevent waste, this clause proved of little value; and in 1860 they again went to Parliament, and obtained clauses which were in effect similar to those already referred to as having been granted about the same time to the Norwich Waterworks Company; while in 1867 some minor additions were made to the Act.

By means of the great powers over the consumer's fittings thus placed in their hands, the Corporation of Manchester have not only been enabled to maintain constant service, but to prevent waste to an extent sufficient to retard considerably the rate of annual increase of consumption.

These cases are examples of the difficulties to be encountered, and of the ineffectual efforts to prevent the waste of water, except in a comparatively slight degree, without almost absolute control over the consumer's fittings and pipes. The provisions in this respect of the Waterworks Clauses Act have not, it is believed, hitherto proved sufficient in any town to enable constant service to be given and maintained, except with a ruinous expenditure of water.

The powers, however, to control waste possessed by the Corporation of Liverpool are, with the following exceptions, limited to those given by this Act.

1. In 1847 it was enacted that the Corporation should not be compelled to supply any water-closet, or the apparatus or pipes connected therewith, which had not been constructed in a manner approved of by the Council.

In an Act obtained in 1850, a clause was introduced inflicting penalties for wilful waste of water.

By the Act of 1862, powers were obtained to cut off the water where anything in contravention of the provisions of the Waterworks Acts was done to lead to waste; and further, it was provided that any person wrongfully suffering any fitting to be so used or contrived as that the water was, or was likely to be, wasted, should forfeit a sum not exceeding £5, and should remove, replace, or alter, or permit to be removed, replaced, or altered, the objectionable fitting or pipe.

Although at first sight they may appear satisfactory, these provisions have been so difficult to work, that, except when waste could actually be proved in each individual case, they have never been enforced.

The difficulty of satisfying a magistrate that a fitting is likely to cause waste is very great; while the necessity for taking into court all cases of waste, in which it is desirable to bring any person under the operations of the last-named provision of the Act of 1862, renders the clause almost abortive. On the other hand, the power to cut off the water supply can only be enforced to a limited extent by a corporation who are guardians of the sanitary condition of the town; and even where this step is resorted to, its effect is to punish the tenant instead of the landlord, who, in houses above £13 rental, is responsible for the work.

The only proper control over fittings or pipes, which the Liverpool Corporation possess, is in connection with water-closets. That control is to a limited extent given, as already stated, under the Act of 1847, and in 1866 it was further provided that every water-closet or urinal should have an apparatus to prevent waste, to be approved of by the Corporation.

When compared with those provisions which had been found necessary to reduce the consumption to any considerable extent in some other towns, it is clear how very little real power over the consumer's pipes and fittings the Liverpool authorities possess.

5. PAST CONDITIONS OF SUPPLY AND DEMAND IN LIVERPOOL.

Before explaining the method lately adopted in Liverpool for the prevention of waste of water, and the results which have attended those measures, the conditions of supply and demand during the last few years will be briefly stated.

In the year 1858, water was for the first time laid on constantly to nearly the whole district, an area of sixty square miles, which the Corporation were bound to supply. The quantity available, under the most unfavorable conditions, was apparently ample, and it might reasonably have been expected to meet the demands of the increasing population for many years to come; but within seven years the people were again subjected to the intolerable annoyance of intermittent service. In August 1865 it was found necessary to reduce the service throughout the borough to twelve hours, in September of the same year to seven, and ultimately to three hours a day; yet, notwithstanding this, the mean consumption for the year was 25.01 gallons per head per day, not including trade supplies.

Various steps were then taken to obtain further supplies; and before 1870 the whole available yield was increased by about one-fifth, by sinking new wells and boring in the New Red Sandstone near Liverpool, and by the purchase of water at Rivington, hitherto given as compensation. Notwithstanding this, however, the average number of hours' service was gradually and of necessity decreased, while the consumption per head did not diminish; and in 1873 it was for the first time found necessary to place the Out Townships, containing 109,749 persons, under intermittent service.

A new supply had been talked about, but many years must elapse before the necessary works could be carried out, while any year might bring with it a dearth of water. Powers for such a supply could only be obtained on condition that constant service would be given; and it had been ascertained by experiments that the average constant service would not be less than 33.5 gallons per head per day, exclusive of trade supplies by meter. Even if the Liverpool people had believed that they were justified in asking for it, with the examples of Norwich, Manchester, and many other towns before them, the fact that so large a proportion of their present supply during twenty-four hours was utterly and harmfully wasted would have constituted a powerful argument in the hands of opposing counsel. The further prevention of waste was therefore regarded as a necessity; while the restoration of constant service, which, it appeared to the Author, ought to be given with the existing supply, was looked upon as a possible concomitant.*

Inasmuch as the great reduction which has taken place in the number of hours' service has been accompanied, in many instances, by an increase of the rate per head, it is not surprising that experiments to ascertain the amount taken during twenty-four hours' service should have indicated that, in 1873, 33.5 gallons per head per day, exclusive of trade supplies, were necessary for the constant service of Liverpool, showing that an increase of 5.2 gallons had taken place in nine years; and although it may not be right to charge the whole of that increment to waste, yet only a small portion of it can be due to extended legitimate use.

To these considerations should be added the fact, that during the same period the trade supplies, measured by meter, have greatly increased.

The number of hours' supply per day must have been still smaller, had not the mean rainfall for several years past been

* Tables are omitted for want of room.

above the general average, and this circumstance had no doubt engendered a feeling of false security, which an examination of the statistics will not justify.

7. EXPERIMENTS IN DISTRICTS COMMANDED BY ORDINARY METERS.

In 1872 the Author had made a series of experiments, with a view to devise means for discovering the locality of a larger proportion of the waste than the house-to-house inspectors were enabled to trace. In carrying out those investigations, the mains supplying fourteen districts in the most densely populated part of the town, containing in the aggregate about 31,080 persons, were provided with ordinary piston meters.

Special house-to-house examinations were made, and the superficial and generally intermittent waste thus discovered was checked; but, although in some districts a marked diminution in the consumption was at the time produced, the results in others were not satisfactory. It appeared, indeed, that in order to detect actual waste in all those fittings which were liable to lead to waste, and thus to bring them, within reasonable time, under the power of the Corporation, it would be necessary, even in this comparatively small section of the town, to employ a large number of inspectors. Further, it was not at all clear that, even if all the fittings liable to lead to waste had been renewed, a very large proportion of the total waste would be prevented.

In four of the districts, which fairly represent the whole, and contain in the aggregate 7,817 persons, it was found, before any special examinations had been made, that while the consumption during nine hours averaged 17.26 gallons; and during twenty-four hours 34.5 gallons per head per day, the rate of flow between 1 A.M. and 4 A.M. was as high as 29.8 gallons per head per twenty-four hours. Moreover, it was ascertained that the rate of this nocturnal flow was constant, while the flow during the day was an ever-varying quantity. This result had been anticipated. The steady flow during the night indicated the rate of waste, while the flow during the day was made up of the waste together with the unsteady flow, due to water being drawn for use. From these figures it may fairly be inferred that 4.7 gallons per head per day, or the difference between the nocturnal rate and the total supply, was approximately the legitimate consumption of water in those districts under constant service.

Assuming what in such districts is very nearly true, that the rate of continuous waste during the nine hours of intermittent service was the same as the nocturnal rate under constant service, the actual amount of that waste during the nine hours was found to be 11.1 gallons per head, while the water taken, being the difference between this and the 17.26 gallons, the total supply during the same time, was 6.16 gallons, or 1.46 gallon per head more than the legitimate use under constant service.

The house-to-house inspections, though persevered in for some time, produced but little effect, and it was obvious that some much less laborious method of detecting the particular fittings causing waste was necessary; while there was a strong impression that a large portion of the continuous waste must be ascribed to other causes than those which the inspectors detected.

The iron mains and lead service pipes in these four disticts were old and shallow, and therefore, before charging the private lead service pipes below ground with the fault, nearly all the public iron pipes and the whole of the public lead service pipes were renewed.

Experiments were then conducted in the following manner:

A district was divided into a number of blocks of houses, each block being placed in charge of a trustworthy man at the same hour, while the occupants were requested not to allow any water to be drawn until they received further notice. As an additional precaution, these men closed and fastened every tap, ball-cock, and other fitting, in order to prevent all use, and so far as possible all superficial waste. The meter resumed its steady rate of movement, and the quantity found to be still passing averaged 7.9 gallons per head per day; while in one of the four districts in question it was as high as 14.5 gallons. Outside each house, under the footways, the service pipes had been provided with stopcocks, and while the fittings were still tied it was found that each individual waste could in nearly every instance be heard, when the street was quiet, by applying the turning key to the stopcocks and placing the ear upon it.

The application of this system of detecting waste has been long known, but it was found impracticable to carry it out successfully during the day, except as an experiment, because it was necessary in each case to tie up and watch the fittings, and because the noise of traffic rendered the sounding operations extremely difficult.

During the night these obstacles did not exist. So long as the Engineer or any of his chief assistants personally superintended the nocturnal work, the results were successful; and by counting the strokes per minute of the meter from time to time it was easy to ascertain the waste, which had been checked by closing those stopcocks through which water was discovered to be passing. The premises connected with such stopcocks being reported on the following morning, became the subjects of examination by the day inspector.

The advantages of the system were manifest, as the labor of discovering waste was reduced, the certainty of discovery increased, and the annoyance to conscientious householders by an ordinary house-to-house inspection removed.

By these means the consumption of water for the whole set of experimental districts, containing 31,080 persons, which under nine hours' service had been 19.5 gallons, and under constant service 33.5 gallons per head per day, was reduced under constant service to 13.3 gallons, and subsequently to about 12 gallons; while in one district of 2,134 persons it was brought down to 6.6 gallons, without altering a single fitting which had not been found to be actually wasting water.

A little consideration showed, however, that, in order to obtain such results over the whole district of supply, including a population of 630,000, in a sufficiently short time to ward off the expected dearth of water and to restore constant service, several districts must be inspected every night. The difficulty of efficient supervision would have been very great, and it would have been impossible to ascertain how far the closing of the stopcocks commanding wasteful property had been faithfully performed, as no record was preserved of the change in the rate of movement of the piston meter, except that returned by the inspectors themselves. The cost, too, of reliable piston meters and of the necessary chambers was at least £112 for each district of about 2,500 persons, while the expense of maintenance was considerable.

8. THE WASTE-WATER METER.

It was under these circumstances that the Author devised an automatic check upon the motions, at once of the night inspectors and of the water, the cost of which is comparatively small. The instrument known as the Waste-water Meter records the time and rate of flow through the main, after the manner in which an indicator diagram records space and pressure. The diagram drawn by the instrument distinguishes water wasted from water used. It registers not only the change of velocity, induced by the closing of any stopcock during the night, but the time at which the men commenced work, and the time at which they ceased work. Such an instrument would, if applied to all service mains, give the means, first, of ascertaining at any time the most wasteful districts, and thus enable the superintendent to concentrate the energy of his men on the streets which most require attention, and subsequently of insuring the efficiency of the examinations during which the waste is limited to a few premises only.

The apparatus has been described elsewhere, and was recently reported upon to the Liverpool Corporation by Mr. F. J. Bramwell, M. Inst. C.E. It is unneccessary, therefore, to do more than explain, that in the instruments now made the diagram is carried on a revolving drum six inches diameter, and is divided by horizontal lines into sixty-two spaces, each of which represents 100 gallons per hour; so that the maximum rate of flow capable of being registered is 6,200 gallons per hour. By vertical lines the diagram is divided into twenty-four equal spaces, each of which passes the pencil in one hour. In the actual sheets the horizontal lines are not quite equidistant.

9. APPLICATION OF THE WASTE-WATER METER SYSTEM.

Arrangement of Distributing Mains.—Although perhaps there are no features peculiar to Liverpool in the manner in which the distributing mains are laid, it is desirable to give examples of their arrangement before describing the details of the Waste-water Meter system.

The principal mains, are charged at all times. From them most of the fire hydrants and larger manufactories are supplied. The subsidiary, or service mains, vary in diameter from two to six inches, and are commanded by valves near their junctions with the principal mains. Of these valves there are about three hundred in the borough, and under intermittent service they were opened and closed every day.

Division into Waste-water Districts.—The existing arrangement of services for distribution is as far as possible adopted. Where, however, a service is too large, it is divided, or a portion is added to an adjoining district, while in some instances, where the services are too small, two or three are combined to form one meter district. Each case is considered in relation to the estimated population, and the anticipated rate of consumption per head, bearing in mind the fact that if the flow at any time exceed 6,200 gallons an hour the diagram will be imperfect. In some cases, after the waste has been greatly diminished on a service, an adjoining district is connected with it, in order to reduce the total number of meters employed.

The largest Waste-water Meter district in Liverpool contains 4,271 persons, the average maximum rate of flow being about 3,500 gallons an hour, and the mean rate per head per day 13.5 gallons.

The smallest meter district contains 870 persons, the average maximum rate of flow being 4,000 gallons an hour, and the mean rate per head per day fifty-one gallons.

The total number of meter districts on the 10th April, 1875, was 120, and the population under control 306,912; so that the average population of the districts was 2,557.

Fixing the Meters.—A district having been selected, a sketch is prepared showing the place the meter is to occupy. A single length of pipe is removed from the outlet side of the service valve, and connecting pipes are laid to beneath the nearest point of the footway and convey the water through the meter. The cast-iron meter cover is placed in the footway next to the kerb.

Diagrams of Initial Consumption.—After a meter has been fixed, readings are taken to ascertain the consumption of water in the district under the ordinary intermittent supply. The district is next placed under constant service, and the consumption ascertained under that system, before any measures for the prevention of waste are commenced. In twenty-four hours a complete diagram is drawn. If the meter is left for seven days, seven complete diagrams will be superimposed upon each other. In such cases the night consumptions are distinct; but the day consumptions, owing to the greater fluctuation, are generally more or less confused. It is therefore usual at first, when particularly accurate information is required, to remove the diagrams every second or third day.

Fixing Stopcocks.—The next step is to attach stopcocks to the lead service pipes of all premises, or blocks of premises, which are not already capable of being controlled from the exterior. The details of the stopcock and its cover are most important; and in Liverpool the existing plugcocks and defective covers have created much difficulty. All new stoptaps are on the screwdown principle, and the loose valve is so arranged that it cannot fall out when the stuffing-box is removed. The surface cover is fixed into the upper side of the flag with Portland cement. The hinged lid is round, and large enough for a man to pass his arm down. Though all new pipes are laid two feet six inches deep, the stopcocks are fixed just within arm's length, in order that a washer may be replaced without opening the ground.

Census Returns.—The number of persons included in the area under test is now to be determined. In residential property a fair estimate can sometimes be made on the basis of the Government census, or by analogy from actual numbering by the water inspectors in another and similar class of property. Where, however, as frequently happens, a satisfactory estimate cannot be made, inspectors are sent to every building to inquire the number of occupants, and in these cases they also examine the fittings, and furnish a report.

Record of Results.—The population having been obtained, the diagrams already taken, both for constant and intermittent service, are worked out, and the results entered in a suitable book.

Night Inspections.—The intermittent and constant service diagrams having been obtained, and the forms filled up, the night inspections, which constitute important features of the system, are commenced. Each day the superintendent of the waste-water department examines the books, and ascertains the three or four districts in which the largest saving is likely to be made. He sends to the night complaint office an instruction for those districts to be visited that night; and the waste-water meter inspector, having obtained the information, places upon the meters commanding each a new diagram paper, which he removes on the following morning.

At about 11 P.M. the inspectors proceed in pairs to their respective districts, where their operations are conducted in the following manner:

Each man takes one side of a street, raises the stopcock covers, and subjects the stopcocks, one by one, to a test, to ascertain if water is passing into the premises. If, on applying the turning key to the stopcock plug and the ear to the turning key, no sound is heard, the stopcock is turned until nearly closed; and if water be passing it will then, by reason of its increased velocity, make a sufficient sound to be heard.

In this manner the flow due to a quick dropping can be easily detected. If noise is heard with the tap open, the tap is at once completely closed, and tested again, when, if the sound is continued. there is evidence of waste on the street side of the stopcock.

It sometimes happens that a number of adjacent stopcocks sound both shut and open. In such cases the inspectors re-examine them, and are generally enabled to ascertain to which stopcock the leak is nearest. Having discovered this, they sound the flags of the footway, and the sets of the carriage way, and in most instances succeed in determining the exact position of the fault.

In other cases several consecutive stopcocks give sound shut or open, until one is reached which sounds when open only, and is most probable the cause of the whole group of sounds. It is closed, and the last stopcocks being re-examined are, if the sounds have ceased, cancelled from the notes.

The exact time of closing each stopcock at which the flow of water is detected is booked by the men, who are provided by the Corporation with watches for the purpose.

When the whole district has been traversed the inspectors retrace their steps, and open the closed stopcocks, after which they return to the office, which they generally reach before 6 A.M., and where they at once write, in copying ink, a report of their night's work.

At 9 o'clock on the same morning a press copy of a night report is ready for each day inspector, who, accompanied by a laborer to open the ground and trace underground leakages, proceeds to ascertain the cause of the noises reported by the night inspectors, and makes his report.

Where the leakages arise from defective private pipes or fittings, notices to repair or renew are issued, unless a new washer or an adjusted wire will do all that is required. In such cases the inspector performs the work free of charge. Defective public pipes are reported, and repaired by the Corporation pipe-layers. The diagram from each district, subjected to an examination on the previous night, is brought to the office daily, and by its aid, in conjunction with the night reports, the superintendent determines the time, within a few minutes, when the inspectors commenced their work and left the district in each case, the localities of all, and the amounts of the more important leaks which have been checked, the initial rate of waste, and the final amount to which the closing of a limited number of stoptaps has reduced that waste.

The diagrams are preserved for reference, in the event of failure to discover the cause of waste at any of the reported points.

Tests for Condition of Mains.—The diagram obtained after a night inspection in any district shows the lowest consumption reached by the closing of those stopcocks, past which a flow of water has been detected. If a margin remains which cannot be accounted for by such trifling leakages as may have escaped the notice of the inspectors, or by leakages reported on the street side of the stopcocks, a special experiment either by day or night is made by the chief inspector to determine the condition of the public pipes. All the stopcocks having been closed, the diagram is examined. If a steady line is being drawn, it is a proof of steady waste. If, on the other hand, the horizontal line is broken here and there by a vertical line, similar to that produced by opening a tap, there is conclusive evidence either that all the stopcocks have not been closed, or that some house services are not provided with stoptaps. In old districts, however great the care on the part of the men, some omissions are in the first instance almost sure to be made; but, with the help of the meter, every service is ultimately controlled.

When the existence of the so-called "public waste" has thus been determined, it can generally be localized by a careful night inspection in which all the stopcocks are closed and sounded. If this is not entirely successful, the sewers are entered, and the position noted of any undue flow down a drain or weeping through the brickwork.

The ground is never opened until the locality of the fault is determined, and mistakes are of very rare occurrence.

The experiments in the fourteen experimental districts commanded by piston meters were commenced in January, 1873, but it was not until October in the same year that the first Waste-water Meters were fixed. In its earlier stages the system progressed but slowly. During the last twelve months, however, it has gained in speed; and, except for the purpose of obtaining the census in some districts, the house-to-house inspections have been entirely abandoned, and no premises have been entered except those in which the night inspections had previously discovered the existence of waste, or to which the attention of the officials had been specially drawn. For some time past twelve meters, controlling about 25,300 persons, have been fixed each month; and it is found that with one chief inspector, twelve ordinary inspectors, six laborers, one Waste-water Meter inspector whose exertions are confined to the meter districts, and two inspectors to attend to special reports in other districts, it is easy to restore constant service to 5,000 persons per week, to sustain it in the old meter districts, and to maintain the average consumption over the whole area supplied at a constantly diminishing rate.

The recent progress of the system may be shown by comparing the circumstances of 1873, of 1874, and of 1875.

In March 1874 about 170,996 persons, and in March 1875, 373,500 persons in the borough were receiving constant supply.

During 1873 the maximum number of hours' service to the intermittent districts in the borough was $10\frac{1}{2}$; the minimum, $7\frac{1}{2}$; and the average, 10. Since then the average has been maintained at $10\frac{1}{2}$ hours throughout the year.

In 1873 the Out Township supply to 91,835 persons was reduced for an average of fourteen weeks to 12 hours per day. Since then constant service has been maintained in the Out Townships.

At the beginning of 1874 the total population supplied was about 621,000. At the beginning of 1875 it had increased to about 632,000.

During 1873 the water taken for all purposes, excepting manufacturers' supplies, measured by meter, was 5,437 million gallons, or 24.42 gallons per head per day. During 1874 the corresponding quantity was 5,478 million gallons, or 23.8 gallons per head per day.

In March 1874 the rate of supply was about 24.21 gallons per head per day.

In March 1875 it was about 22.26 gallons per head per day.

Actual Saving of Water.—It is to be regretted that comparatively few persons apprehend the importance of the work in progress, with anything like the eagerness which would be evinced if the reduction in the rate of waste, instead of being chiefly manifested by the restoration of constant service, were shown in the actual figures of water saved, as would be the case if Liverpool had in 1872 been receiving constant supply.

Fortunately the meters give the means of determining the actual saving in water, on the assumption that the town was receiving constant service from the beginning.

In nearly every waste-water district, the quantity of water taken, under the constant system, has been determined before disturbing the initial rate of consumption.

The number of persons to whose service the Waste-water Meter system has been applied in Liverpool, to the 10th of April, 1875, is 234,000, but many of the districts have as yet received little attention at the hands of the night inspectors. Taking that moiety of the districts to which attention has been chiefly given, the supply to 117,425 persons, which under constant service averaged 32.12 gallons, has been reduced to 15.97 gallons per head per day. If the whole population under treatment be considered, the rate per head per day to 234,000 persons, is found to have diminished from 28.89 to 16.47, which is equivalent to a total saving of 1,060,792,200 gallons per annum.

It is known, by experiments in a few isolated cases, that the waste in these districts may be still further reduced; but the Author systematically avoids occupying the inspectors' time in those portions of the town to which constant service has been restored, except so far as it is necessary to do so, in order to keep down the total consumption, as district by district the change is made.

In comparing the rate of consumption per head per day in Liverpool, with that of other towns, the following considerations must not be lost sight of:

Unlike most towns in which constant service has been given and maintained at a low rate of consumption, the inmates of four-fifths of the houses are provided with water-closets.

The term "domestic consumption" has been somewhat improperly applied and has a much wider signification than in most other towns, as it includes all supplies for sanitary purposes, and a large proportion for business purposes. In other towns it is usual to confine the term to the use of water in private dwellings only; and this difference would be equivalent, in most cases, to several gallons per head per day.

The system described has been tried in every class of property; and in some districts containing the best houses the saving of water has been quite as great as in any others. It is certain, moreover, that the most wasteful districts have not yet been reached, and there is every prospect of a rich harvest during the present year.

10. RELATIVE ADVANTAGES OF THE WASTE-WATER METER SYSTEM AND OF THE ORDINARY HOUSE-TO-HOUSE INSPECTIONS.

The policy of the present practice differs chiefly from that of the old system in four particulars:

1. By never employing inspectors in any but those districts in which the meter diagrams show that the best results are likely to be attained. As the following facts illustrate, this alone is a great desideratum.

Out of a hundred waste-water meter districts, several cases have been chosen in order to show how widely the consumption and degree of waste differ in districts of the same age and class, before any special work has been attempted in connection with them. The dark figures are cases of large consumption, and the light figures of small consumption in similar districts. (See table next page.)

In the examples given there was nothing whatever to lead to the belief that any of the districts in dark figures would constitute more fruitful ground for the labors of the inspector than those in light figures. Under the ordinary system both would have been examined alike, and the energies of the inspectors in a great measure wasted.

2. By never employing inspectors to examine any premises in which it has not been previously ascertained that waste is taking place.

Although, as already stated a great desideratum would be gained by adopting house-to-house inspection, but confining it to those districts only from which the meter diagrams show that the best results would be obtained, the advantage is greatly increased by abandoning regular inspections even in those districts, and by adopting means, such as have already been described, to ascertain in which premises waste is actually taking place.

With far better methods for detecting waste at their disposal than the house-to-

Number of District.	Population.	Consumption per Head per Day.		Remarks.
		Average.	Night Rate of Waste.	
		Gallons.	Gallons.	
270 and 271.....	1,319	40.6	30.4	Adjoining districts resembling each other in every respect.
258 and 264.....	2,778	11.8	7.3	
254.............	2,082	40.7	33.8	Ditto.
266.............	1,661	14.67	9.1	
259.............	2,765	16.0	9.13	
14.............	838	41.0	34.1	Similar class of property, but the district which gave the higher rate of consumption would have been supposed to be less wasteful than the other, owing to many of the fittings being of a better class.
18.............	4,012	15.8	12.5	
8...............	827	45.0	35.5	Districts in the same locality and property similar.
7...............	2,570	55.0	45.6	
15.............	2,377	13.6	8.5	
237.............	2,261	54.8	44.5	Ditto.
262.............	3,430	11.5	7.37	

house visitors have even possessed, the night inspectors of Liverpool do not, as a rule, find on an average more than about one leak at every tenth house.

The annoyance to the inmates, therefore, and the loss of time is in nine-tenths of the cases avoided, while the fact that in or under each house visited by the day inspector who follows up the night reports, a leak certainly existed on the previous night, is an incentive to the discovery of the source of waste which under the ordinary system cannot possibly exist.

3. By the detection of the more important, because the more continuous, sources of waste which are rarely discovered by house-to-house visitations.

It has been shown, that in some of the experimental districts a large portion of the waste was of a kind the source of which could not be detected by ordinary house-to-house inspections.

For the purpose of ascertaining the respective advantages as measured by the quantity of waste discovered by house-to-house visitors and by night inspectors, a number of districts in various parts of the town have been taken at random. The ordinary day inspections were made after the meters were fixed, and particular care was taken to insure their completeness, not only by examining the fittings and pipes thoroughly, but by testing the fittings by sounding. They show generally that the effect on the consumption thus produced, after subsequent examinations to ascertain that the defects discovered had been repaired, was to reduce the demand from a night rate of 20.6 gallons to 17.3 gallons per head per twenty-four hours.

Immediately the results of the day inspections had been ascertained, night inspections had been made, and it was found from the diagrams that a further diminution in the consumption of seven gallons per head per day was thus produced.

In other words, where the most careful day inspection reduced the consumption from 20.6 gallons to 17.3 gallons, a night examination, if substituted for it, would have reduced the consumption from 20.6 gallons to 10.3 gallons.

The same advantages are also shown in a striking manner by comparing the proportion of waste detected by the inspectors in the past with that discovered by the night inspections.

In 1863, when the proportion of inspectors to a million persons was 3.86, the proportion of the leaks discovered from defective fittings and pipes to the number of premises visited was 14.1 per cent.

In 1870, after the system had been in operation for seven years, and when the proportion of inspectors to a million persons was 17.12, the proportion of the leaks to the premises visited was only ten per cent.

In 1872, when the proportion of inspectors to a million persons was 28.12, the proportion of the leaks to the premises visited was only nine per cent.

The special house-to-house visitations subsequently carried out under the more favorable circumstances in the districts referred to above, which are fair examples of the whole, when the proportion of inspectors to a million persons was 25.2, indicate that the proportion of the leaks to the premises visited was 12 per cent.; the diagrams at the same time showing that the repair of these leaks produced a reduction of 3.36 gallons per head per day in the night rate.

But in those very districts in which so high a proportion of waste had been checked, night examinations under the meter system, made immediately afterwards, detected an additional proportion of leaks to premises of 8 per cent., and an actual additional waste of 11.15 gallons per head per day.

An analysis of the returns of the day inspectors, made upon the reports from the nocturnal examinations, shows that the additional and much larger waste thus detected, though continuous, was attributable to causes which the house-to-house inspectors must necessarily have failed to detect.

A large proportion of the leaks thus discovered are due to defective pipes underground, and of these a few samples are exhibited, with notes as to the circumstances under which they were discovered, and the quantity of water which each will pass at 50 lbs. pressure.

4. By never renewing old mains except when the meter diagrams have shown that they are actually causing waste to an extent which justifies the expenditure.

In many waterworks the distributing mains are of all ages, and being, in a greater or less degree, constant sources of unseen waste, it is usual to spend a sum of money annually for the renewal of those which are believed to be the oldest, or which may have happened to show their deficiencies by leaks appearing above the surface of the ground. Only those who have tried it by absolute measurement can form any idea of the fallacy which commonly obtains in reference to this matter. In Liverpool it has been found that the number and importance of the defects in mains, which continue for years without giving any superficial indication of their existence, is very great. Experienced managers of waterworks have expressed the opinion, which was until recently shared in by the Author, that a main could not break across without revealing the fact in a short time. But the present system has brought to light many instances of broken mains in which the sharp edges of the fracture have been worn off in the course of years by water under a head of 100 or 150 feet. The other chief causes of waste from the mains are wooden plugs in old ferrule-holes, either driven out by the water or leaking, wooden plugs partially decayed, which were formerly used instead of iron caps on the ends of mains, and blown lead joints. On the other hand, most of the oldest mains, although they are fractured by the slightest disturbance, and are liable at any time to lead to great loss, are perfectly tight, and might remain so for years.

It is, therefore, an obvious economy to have a better means of ascertaining their condition, and thus to gain maximum and immediate results, by the prevention of waste, from money the interest or great part of which was formerly lost for years.

11. COST OF APPLYING THE WASTE-WATER METER SYSTEM.

Where stopcocks on the service mains do not already exist, either inside or outside the houses, it is obviously desirable that they should be fixed, if only to avoid the great inconvenience arising from having to cut off the water from a large district each time a repair to any pipe or fitting becomes necessary. In Liverpool the work of fixing stopcocks had been commenced before the meter system was introduced; but, inasmuch as stopcocks outside the houses are necessary for the complete development of the system, the cost of providing them will be considered here.

In Liverpool, as in most other towns, a certain number of stoptaps, but probably only about one-fourth of the number required, already existed.

The cost of providing and fixing each

new stopcock, including the surface cover, reflagging, renewing defective flags, and searching for the service pipe, is about 12*s*.

The average number of persons to each meter is 2,557.

The cost per thousand persons in a town in which stopcocks are already laid would average for the meter and fixing £14 7*s*. If, however, as in the case of Liverpool, the greater proportion of the stopcocks have to be charged to the system, the cost, including the meter, would be about £39 7*s*. per thousand persons.

The necessary plant having been provided, the operations for the prevention of waste immediately show a great reduction of expenditure.

The staff of inspectors has been somewhat reduced since the system was commenced, but there are no means of comparing accurately the water saved in each case, though it is obvious from a general comparison of the results under the two systems that a small fraction of the old staff would, under the district system, have performed more work, while no increase in the numbers of the original house-to-house inspectors could have effected the saving since obtained. A clerk's time for about four hours a day is occupied in computing the diagrams and recording the results, but the number of turncocks has been diminished by three, so that on the whole the staff has been reduced.

12. TREATMENT UNDER THE WASTE-WATER METER SYSTEM AFTER THE RESTORATION OF CONSTANT SERVICE.

It has been already stated in effect that during the last twelve months all pipes and fittings, with the exception of those actually leaking in the meter districts, or reported by the public, have been left to themselves. Notwithstanding the greater proportion of waste which those pipes and fittings therefore occasion, and notwithstanding the fact that in the waste-water districts it was necessary to save twelve or thirteen gallons per head per day on the initial constant supply before the consumption could be reduced to the same amount as the initial intermittent supply, it has been shown that a reduction in the total supply per head per day has been effected, and it has been further stated that the rate is gradually diminishing.

From these facts it is reasonable to conclude that when constant service has been everywhere restored, and the water saved, whatever it may be, is no longer absorbed in making up the difference between intermittent and constant service, but effects an immediate reduction in the total supply, the staff required to maintain or even to diminish the comparatively low consumption will be considerably less than at present.

From experience gained in the districts already under control, there is reason to believe that, in order to keep a proper record of the condition of the whole of the town, it will then only be necessary to take on the average one meter diagram for three or four days per month from each district. The total number of districts, including in the aggregate 632,000 persons, will be about 250, and the number of diagrams per day, including those from districts under examination, will probably not exceed 20.

Each day, two or three districts of maximum waste will be provided with new diagrams, subjected to night examinations, and when brought below the average consumption, replaced on the ordinary list, and only provided with new diagrams when the district of which each forms a part is visited in its monthly turn.

13. TESTING AND STAMPING FITTINGS, AND INSPECTING NEW WORK.

A very important section of the work in connection with the prevention of waste is that relating to the class and quality of the pipes and fittings fixed in new premises, and substituted for those which have been prohibited. However good the fittings may be, it is certain that, unless some supervision is exercised over them by the authorities, large numbers will become, and continue to be, defective. If, however, they are satisfactory to begin with, only trifling repairs, easily effected, will in the large majority of cases be necessary.

It has already been stated that the power of the Liverpool Corporation to prescribe the details of water fittings is very limited, and by way of insuring the execution of their requirements in cases of new fittings, they have adopted, with some modifications in detail, the system of testing and stamping fittings, and of advertising the names of those plumbers who agree to conform to their regulations, which has been successfully applied by the Manchester Corporation; with this difference, however, that the latter body have parliamentary powers to license the plumbers approved of.

In March 1873 the Liverpool Corporation invited each plumber to sign an agreement, undertaking that all work performed by him should be in conformity with the rules and regulations of the Water Committee.

The Corporation, on their part, place the names and addresses of such plumbers on the waste-water notices, and recommended them in preference to others. Nearly all the plumbers whose names appeared in the Liverpool Directory signed the agreement, and in comparatively few cases have the rules been infringed.

The published regulations, drawn up in 1873, have recently undergone some slight alterations, which experience has shown to be desirable. In their modified form they appear to work well.

In the testing office a superintendent with one assistant and two boys are employed, whose duty is to examine each fitting superficially, and to ascertain that it apparently works satisfactorily. If a tap or ball-cock, to place it in jaws, provided with the means of supplying water at a pressure of 300 lbs. per square inch. If a regulating cistern or service-box, to ascertain by actual trial with water that the valves work truly, and that the delivery valve passes the 2-gallon flush in less than fifteen seconds. To weigh, gauge, or examine every part of each fitting, including valves, valve-seats, washers, valve-rods, and, in the case of alternating-valve regulating cisterns, to see that the valves have the prescribed lift, and that the lever has the prescribed play between the respective lifts. And to stamp those fittings only which are in all respects in conformity with the samples kept for exhibition.

Any person who desires to introduce a new description of fitting, or even a change in the form of an existing sample, is required to send it, not to the testing office, but to the Engineer. If after undergoing examination, and being subjected to such tests as are thought necessary, it is considered no less satisfactory in principle, quality, and workmanship than the general standard hitherto adopted, it is placed among the sample fittings, and may thenceforth, unless, of course, protected by patent, be copied by any other maker. No licence is given to the superintendent of the testing department to allow deviations in any respect from the adopted standard in each case.

At first sight, this great stringency may appear unnecessary. On the introduction of the system into Liverpool, some latitude was, however, given to the testing officer, and the consequence was that each maker endeavored to undersell his neighbour by trifling reductions in the material and in the quality of workmanship. Thus step by step the standard was reduced, until at last it became necessary to insist that no change whatever should be made, unless one of the altered fittings was accepted as a standard sample.

The present system allows fair competition, and encourages the ingenuity of manufacturers.

Clause A of the Regulations requires all authorized plumbers to fill up, and leave at the engineer's office, printed forms as notices that new or altered pipes or fittings are ready for inspection, and such notices are required to be given before pipes or fittings are covered.

Notwithstanding the satisfactory working of this system, by which it is made the interest of the plumber to do his work well, it must be allowed that in connection with old fittings difficulties frequently arise, for the removal of which an Act of Parliament should be obtained.

CONCLUDING REMARKS.

The Author has endeavored to show the results of his experience in connection with a system for preventing waste, which has hitherto produced practical results in Liverpool only.

It has been necessary in many instances to refer to special districts, in order to explain particular points, and such districts have been selected as represent the results fairly, so that the remarks upon them are applicable generally to all similar districts.

In low-class districts of the metropolis the waste of water is probably even greater on the average than in Liverpool; but if constant service were restored to any single district, that very fact would in a great measure create its own cure. Many of the outlets for water, which under a few hours' supply are left continuously open, would, under constant supply, become such intolerable nuisances that the flow must inevitably be checked; and if the owners of property became aware that all cases of continuous waste would certainly be discovered by the night inspectors, and watched by the authorities until the cause was removed, in the manner which they might prescribe, the district would soon show a lower consumption than under intermittent supply.

In a system the success of which depends so much upon the careful and politic manner in which the details are attended to, it is obviously necessary that the control of such details should be delegated only to those whose energy and general qualifications render them peculiarly fitted to lay aside the ordinary practice in such matters, and to enter vigorously upon the new processes.

NOTE ON PROF. MERRIMAN'S CALCULATION OF STRAINS IN THE CONTINUOUS GIRDER.

By JOHN D. CREHORE.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

INCIDENTAL to other calculations which I am making for strains in the continuous girder, I have applied my method to Professor Merriman's example of five unequal spans, given in this Magazine for September, 1876. In his solution for the third span there is one point (probably an oversight) to which I would call attention.

On the 193d page he defines W as "being equal to wl, if w is the load per linear unit;" and with this understanding he writes $A=\frac{1}{4}Wl^2$. Upon the 198th page he puts $W_1=6\times8=48$, for six apex loads, $W_2=9\times8=72$, for nine apex loads, etc.; and "considers the live loads applied at the panel-apices, as uniformly distributed over the spans."

Now, is it correct to consider the sum of these apex loads on any span, as uniformly distributed in the sense in which W has been defined? If it is correct, then in this example we have:

Ton per linear foot.

1st span, $\frac{W_1}{l_1}=w_1=\frac{48}{70}=0.6857$

2d span, $\frac{W_2}{l_2}=w_2=\frac{72}{100}=0.7500$

3d span, $\frac{W_3}{l_3}=w_3=\frac{56}{80}=0.7000$

Tons per linear foot.

4th span, $\frac{W_4}{l_4}=w_4=\frac{88}{120}=0.7333$

5th span, $\frac{W_5}{l_5}=w_5=\frac{64}{90}=0.7111$

whereas there are, actually, eight tons to every ten feet, except at the end half-panels of each span.

The formula, $A=\frac{1}{4}Wl^2$ is strictly applicable to apex loads, only when the apices are infinitely near each other; in which case we should have, if $w=0.8$,

$$\frac{W}{l}=w\times\frac{l}{n}\times\frac{n-1}{l}=w=0.8,$$

when n, the number of panels, is infinite.

The two formulae,

$$A=Pl^2(2k-3k^2+k^3),$$
$$B=Pl^2(k-k^3),$$

which the Professor has used for the apex loads on the third span, are equally required in determining the pier-moments of that span, due to the apex loads on the 1st, 2d, 4th and 5th spans.

For full loads these two formulae give identical results, and the tedious summation of numbers can be avoided by first summing the series.

Thus, for any span covered with the

live load alone (if this were possible) we should have:

$$A=B=Pl^2\Sigma(2k-3k^2+k^3)=Pl^2\Sigma(k-k^3)$$
$$=\tfrac{1}{5}l^2-20\,l=\tfrac{1}{4}\,Wl^2-20\,l,$$

where $W=nP=0.8\,l,$

$$l=10\,n,$$

$$k=\frac{1}{n},\frac{2}{n},\frac{3}{n},\ \ldots\ \frac{n-1}{n},$$

For clearness, I tabulate the values of A and B, resulting from their different conditions of loading:

	$\frac{1}{4}Wl^2$ 0.8 ton per lin. ft. continuously distributed uniformly.	$\frac{1}{4}Wl^2$ $\frac{0.8\,(n-1)}{n}$ ton per lin. ft. continuously distributed uniformly.	$Pl^2\Sigma(k-k^3)$ 8 tons at each lower apex, or joint.
$A_1=B_1$	68,600	58,800	67,200
$A_2=B_2$	200,000	180,000	198,000
$A_3=B_3$	102,400	89,600	100,800
$A_4=B_4$	345,600	316,800	343,200
$A_5=B_5$	145,800	129,600	144,000

Now it is manifest that the third column of numbers alone, answers the conditions of the example we are considering; and for the third span our author has used 100,800, instead of 89,600; but for the four other spans he has drawn from the second column instead of the third.

Computing the moments in the third span by using the third set of values of A and B, just given for spans fully loaded, and the values of A and B, which Mr. Merriman has given for the seven separate apex loads on the span, we have the following table:

(*See Table on following page.*)

When this table of moments and strains is compared with that on the 201st page of the September Magazine, the value of my criticism will be sufficiently apparent.

I have called attention to this subject not so much because Professor Merriman, in the case of four spans, inadvertently distributed his apex loads uniformly from pier to pier, as because I have perceived in the practice of some engineers (?), a tendency to treat the apex loads as uniformly distributed continuously, *in order to find the strains as small as possible,* and thus underbid (if the doctrine be accepted) competitors who do not employ that device.

It will be noticed that I derive each maximum diagonal strain, not from its vertical, but from its horizontal component, furnished directly by the sum of the positive or negative differences of simultaneous moments at adjacent lower joints. This obviates the use of "shears" altogether, in the present example.

Thus, for the third pair of braces, the sum of the positive differences of simultaneous moments at the 3d and 4th joints, is

$$\Sigma\,(\Delta M)+=303.3.$$

Then 30.33 is twice the horizontal component of the brace-strain sought; and the strain is

$$30.33\times\frac{2.236}{2}=33.9.$$

Simultaneously $\Sigma\,(\Delta M)-=-76.3$; and the strain due this negative difference is -8.5.

In summing these differences, the difference due to dead load, must, of course, be always present with its proper sign.

The maxima strains in the bottom chord, I also deduce directly from the moments and strains already found, and thus avoid computing and arranging another table.

In the girder under consideration, it is plain that any panel-length or segment of the bottom chord, will sustain its maximum strain simultaneously with the maximum strain in either one or both of the segments directly above it in the upper chord.

If the strains in two adjacent segments of the upper chord, are both maxima for the same conditions of load, then the maximum strain in the segment of the bottom chord, directly below, will be a mean between the two upper strains. Thus for the third segment of the bottom chord,

$$H_3'-=-\frac{41.2+38.6}{2}=-39.9.$$

$$H_3'+=-\frac{-23.5-43.6}{2}=+33.6.$$

after changing the signs.

If the strains in two adjacent segments

		M_3	10	20	30	40	50	60	70	M_4
1	6 P	−63.1	−53.5	−43.9	−34.3	−24.7	−15.0	−5.4	4.2	13.8
2	9 P	446.4	378.4	310.4	242.4	174.4	106.4	38.4	−29.6	−97.7
3	P_1	29.1	−43.2	−35.4	−27.7	−20.0	−12.3	−4.6	3.2	10.9
4	P_2	45.3	−17.5	−80.3	−63.1	−45.9	−28.7	−11.5	5.7	22.9
5	P_3	50.8	− 1.3	−53.4	−105.5	−77.6	−49.7	−21.8	6.1	34.0
6	P_4	47.9	7.2	−33.6	−74.3	−115.0	−75.8	−36.5	2.8	42.0
7	P_5	39.1	9.8	−19.5	−48.8	−78.1	−107.4	−56.7	− 5.9	44.8
8	P_6	26.6	8.3	−10.0	−28.3	−46.6	−65.0	−83.3	−21.6	40.1
9	P_7	12.8	4.4	− 3.9	−12.3	−20.7	−29.0	−37.4	−45.7	25.9
10	11 P	−171.3	−61.4	48.5	158.4	268.3	378.1	488.0	597.9	707.8
11	8 P	28.8	10.3	− 8.1	−26.6	−45.0	−63.5	−81.9	−100.3	−118.8
12	Live }	726.7	418.4	358.9	406.8	442.6	484.5	526.4	619.8	942.2
13	Load }	−234.4	−176.9	−288.2	−420.9	−473.6	−446.3	−339.0	−203.2	−216.4
14	Sums...	492.3	241.5	70.7	−20.2	−31.0	38.2	187.4	416.6	725.8
15	Dead l'd	369.2	181.1	53.0	−15.1	−23.2	28.7	140.5	312.4	544.3
16	Max. +	1095.9	599.5	411.9	385.6	419.4	513.2	666.9	932.2	1486.5
17	Max. −	..	..	−235.2	−436.0	−496.8	−417.6	−198.5	..	..
					TOP	CHORD.				
18	H +	109.6	59.9	41.2	38.6	41.9	51.3	66.7	93.2	148.7
19	H −	..	..	−23.5	−43.6	−49.7	−41.8	−19.8	..	..
					DIAG	ONALS.				
20	$\Sigma(\Delta M)+$	558.4	426.1	303.3	191.3	90.5	1.2	..	..	..
21	$\Sigma(\Delta M)-$	..	..	−76.3	−164.2	−263.5	−374.2	−495.9	−627.5	..
22	Odd }	−62.4	−47.6	−33.9	−21.4	−10.1	−0.1	..	..	..
23	brace }	..	..	8.5	18.4	29.5	41.8	55.4	70.2	..
24	Even }	62.4	47.6	33.9	21.4	10.1	0.1	..	..	..
25	brace }	..	..	−8.5	−18.4	−29.5	−41.8	−55.4	−70.2	..
					BOTTOM	CHORD.				
26	H′+	..	..	33.6	46.6	45.7	30.8	..	..	..
27	H′−	−81.7	−45.5	−39.9	−40.3	−46.6	−59.0	−77.4	−117.3	..

of the top chord become not maxima simultaneously, take the maximum value of each, and find from the table the simultaneous value of the other; and in either case take the half sum. The greater half sum will be the lower segment strain sought, after changing its sign. Thus when

$$M_{10}=\text{max.}=599.5,\ M_{20}=288.2;$$

therefore

$$H_2=59.9 \text{ and } H_3=28.8.\quad \tfrac{1}{2}\text{ sum}=44.4.$$

When

$$M_{20}=\text{max.}=411.9,\quad M_{10}=498.1;$$

therefore,

$$H_3=41.2 \text{ and } H_2=49.8,\quad \tfrac{1}{2}\text{ sum}=45.5;$$

whence

$$H_2'=\text{strain in lower chord}=-45.5.$$

THE WELDING OF IRON.

From "English Mechanic."

The following abstract of a paper by Mr. G. Newcombe, the secretary of the Cleveland Iron Trade Foremen's Association, will be found a valuable addition to the literature of a subject which has recently attracted much attention. Mr. Newcombe calls attention to the ambiguity of language in which the conditions for an effective weld are often stated, and introduces extracts from some of the latest utterances on the subject. Mr. Edward Williams, at the conclusion of a paper "On the Manufacture of Rails," read before the Iron and Steel Institute in September, 1869, said: "Welding I hold to be the one thing needful, and we should never lose sight of it. As I have before said, the chance of obtaining thorough welding would be much increased by not insisting on more toughness and fibre than is absolutely necessary to guard against so much brittleness as would bring about breakages of the rail in work."

In the discussion on that paper, Sir William Armstrong said that "in the manufacture of guns on the coil system, a perfect welding is just of as much importance as it is in the manufacture of rails. The conclusion arrived at, both at Elswick and Woolwich, was this, that in proportion as the iron has a steely character, so in proportion is it unfavorable for welding. The indication of its steely character was obtained in this way: We took a specimen of iron heated to a certain point and then plunged it into water. If we found its tensile strength was increased beyond a certain limit it was rejected as unfavorable for welding. The iron welds most perfectly which undergoes no increase of strength in the process of hardening."

Wr. Williams, in reply to questions, said, "Mr. Fothergill has asked me what welding is. I believe good welding to be a combination of effects, an actual amalgamation of the surfaces, and soldering together by means of the cinder. In proportion as we have more of the absolute contact and less of the soldering, so is welding good, and *vice versa.* Where there is no contact of the actual metallic surfaces, and nothing but the soldering of the layers together by means of the cinder, we have poor welding; and it is the poorer the thicker the cinder. Where you have a large proportion of surface actually brought in contact with the layer next to it, then you have what we call good welding. But, so far as I know, perfect welding—that is, complete contact of surfaces, or anything at all approaching it—is impossible."

I will now give a quotation from another source. Mr. Mathieu Williams, in his fifth Cantor lecture, in treating on lamination and blistering, says: "When a blacksmith makes a weld in a common open fire, he throws sand on the surface to be joined, the object being to flux the scale—that is, to convert the oxide into fusible silicate. This being done, he brings the fluxed surfaces together, and by hammering forces out the liquid silicate, and thus brings clean surfaces of pure iron together, which at a proper heat unite perfectly. If he had a film of oxide between the surfaces it would prevent welding. Following up this principle, I obtained from the potteries some "slip," or finely-ground flint used in glazing earthenware, mixed this with sufficient water to form a sort of paint or whitewash, and with a whitewasher's brush painted it over the surface of the piles on both sides of each layer. I treated several piles of the finest quality of iron in this manner:—They were rolled into boiler-plates, none of which showed any signs of lamination. I believe that by this means lamination may be effectually prevented."

Further, at the meeting of the Iron and Steel Institute, held at Leeds in the autumn of last year, Mr. Richard Howson, in a paper read before that society, "On Welding Iron," said that in order to obtain "complete metallic contact" the skill of the workman had to be exercised—1st, in heating the iron sufficiently; 2d. in protecting the surface from oxidation by means of a flux; 3d. in forming the surfaces in such a way that the flux has a means of escape when the ends are closed up under the hammer.

Having thus given you a *résumé* of the latest theories on the subject of our paper, I propose, with your permission, to examine them from a practical standpoint, and ascertain how far they are supported or contradicted by the most advanced practice of the day; and as Mr. Howson's views are of the most recent date, and may fairly be supposed to include much that had previously been said on the subject, I propose to take up the consideration of his conditions—first, on the necessity for proper heats to secure good welds. I have no doubt we shall all agree on this condition; in point of importance I think it rightly stands first, for I believe if the primary cause of defective welding could be traced, its origin would in a majority of cases be found in bad heating.

There are other causes which prevent

good welding, but I shall treat of them in another place. There is no operation connected with smithing which requires more careful handling, or gives more anxiety to the smith, than the process of welding, for on the successful issue of one weld in the manufacture of a single article may depend either the success or loss of much labor and money. It may, therefore, repay us to examine with care the conditions to be observed in obtaining a good heat. In the first place the fuel must be as free from metallic impurities as possible, especially sulphur, as it readily combines with iron, and with it forms sulphide of iron, which is naturally detrimental to the formation of a good weld; 2d, by a proper construction of the hearth, and arrangement of tuyere, to obtain the requisite chemical combination necessary for a proper combustion of the fuel for heating purposes. This is effected by placing the tuyere about four inches below the level of the hearth for lighter kinds of work, and from six to eight inches for heavy kinds. But even with good fuel and the arrangement of tuyere just spoken of we may obtain two kinds of heat—viz., a carbonaceous or reducing heat, or an oxydizing or destroying heat; the carbonaceous is that which is required by the smith to reduce his iron to a welding condition, to obtain which he must maintain a constant supply of heated fuel between his tuyere and the iron to be heated, and covering it likewise if the whole mass is to be heated. The chemical action which here takes place may be explained thus :—The oxygen of the air, after passing the tuyere, comes in contact with the heated carbon in the fuel; chemical union then takes place; one part of the carbon combines with two parts of oxygen, forming carbonic acid; this, in passing through the heated fuel above it, takes up another part of carbon and forms carbonic oxide, which is composed of two parts carbon and one part oxygen; and so long as this action can be maintained we have a reducing heat suitable for bringing iron into the welding state with the formation of the least amount of oxide on the surfaces of the iron; and if we fail to obtain those conditions, and allow the fuel to become deficient in quantity between the tuyere and the iron when it is in a semi-welding state, then we have a chemical action of a different kind, for the oxygen then being in excess, through a deficiency of carbon, readily combines with the iron, and forms a cinder or oxide of iron. This combination results in great loss of iron, as will be seen in the following example, which shows a portion of a $\frac{5}{8}$ square bar of iron that has been heated to a welding condition and then placed under a blowpipe. A high heat was maintained for nearly two minutes by simply turning the different sides of the bar to the action of the oxygen. The iron in this condition appears in a boiling state, and the oxide formed ran off in small liquid globules.

If the destructive effect of oxygen is so apparent on a small sample of iron, an approximate opinion may be formed of the great loss resulting from its action on large masses. I believe that in proportion as we obtain heats under either of the two conditions just named, so shall we get good or bad welding. If the oxydizing heat has acted on the iron, it leaves a film of cinder which is difficult to remove, and which prevents close metallic contact of the molecules needful to good welding; this is often apparent in examining large forgings, when turned and polished, that have been laid together or built up in slabs or piles. A dark horizontal line may be traced in the forging which indicates the junctions of the slabs that in heating have been allowed to oxydize, perhaps through the furnace being too slow in heating, or through the admission of too much free oxygen. The oxide not being properly expelled while under the hammer, the result is a defective shaft, the weakness of which is soon made apparent if in performing its work it is subject to much torsion; whereas, if the mass had been heated in a full carbonaceous flame to that fine mellow or spongy condition so essential to a complete incorporation of the molecules, and which renders iron as nearly homogeneous as can be obtained under the piling system, no such thing would happen.

We will now examine the second section of the conditions just quoted as necessary to secure good welding—viz., in protecting the surfaces from oxidation by means of a flux. The views advanced in this section of the author's argument are so utterly at variance with the best practice of modern times, that I feel compelled to join issue with him on this subject, as I am convinced that it is not necessary to use any flux in order to secure a perfect weld—that is, if the iron is comparatively free from carbon, and the proper conditions of heating have been observed. Large masses of scrap are welded up in our forges, and smaller sections of iron in our smithies without any flux. Indeed, I have no doubt in the process, described by the author, of piling and rolling the large armor-plate at Sheffield, and the lucid description of the manner adopted at Low Moor in manufacturing their famous plates and bars, shows that no silica was used as a flux to assist the welding other than that which the iron contained when it left the puddling furnace; yet the author admits that his samples were as nearly homogeneous as it is possible to get them without absolutely melting the iron. That welding may be effectively accomplished without the use of a flux I think there are few workers in iron prepared to dispute; but as fluxes are used in welding, and chiefly by smiths, we will inquire into the cause of their adoption.

The flux chiefly in use is sand; being abundantly found in nature it is consequently cheap. It is composed of silicon and oxygen, and technically known as silica. It readily melts on being applied to hot iron; and it is this property, combined with its cheapness, that accounts for its general use. Why is it used by the smith? Because in joining two pieces of iron together different kinds of splicing or scarfing are adopted; those, or at least the most common in use, are of a pointed character, and they present an unequal thickness of iron to the action of the heat; and as the point of the scarf is farthest into the fire, and through its unequal thickness conducts the heat much quicker than the heel or thick part of the scarf, it consequently arrives in a welding state first, and if the action of the heat was not checked the point would be burnt away before the heel had arrived at a welding state. To prevent this the smith throws on or dips the back of the point into the sand; the sand on coming in contact with the heated iron melts and absorbs so much of the heat of the part to which it is applied, and on melting becomes vitrified. This glassy silicate readily combines with the iron, and forms a covering to the part exposed to the heat, and being of a very refractory nature, it is some time before it is burnt off the iron. It thus protects the iron in its weak or exposed part, while the other or thicker part is absorbing the heat and arriving at the welding condition. It is sometimes used when the iron is on the anvil, but only when such iron is overheated, and will not bear hammering. A little sand thrown on absorbs the heat and restores its cohesive power. The smith, in using sand, is always careful to keep it from the face of the scarf; he knows from experience that the cleaner he keeps the two surfaces to be welded the closer and more perfect will be the weld. This, I consider, is the legitimate use of sand in welding; it is used as a chemical agent to prevent waste of iron, and even in this capacity should be used as sparingly as possible, for its baneful effects are left behind on the forged articles, which, if they have to be either planed or turned, present on their surfaces a series of knotty or flinty points which blunt the tool and are a source of much annoyance to the operator.

I believe that the use of sand is injurious to iron, and though I admit that it may be used as an agent to prevent waste of iron in some particular kinds of scarfing, I contend that it is not essential to sound welding. In support of this assertion, and keeping clear of the examples before me, I will refer to the welding of tires for railways and tubes for boilers; both these articles are continually under inspection for the purpose of detecting flaws or unsoundness, and they are subjected to continual tensile strain and shocks which tend to develop any flaws or unsoundness, yet how few out of the many thousands in use give way at the weld! and they are invariably welded without any flux being used. Numerous other examples might be given of specialities of manufacture where the welding is done without any flux, but I think they would not add any more weight to the argument I have here advanced.

Before closing this subject there is one matter nearly connected with welding which has not received that careful attention that it demands, and which, I think, the future interests of the district will require. I refer to the selecting of iron suitable for welding properly together; not that there is any difficulty in welding the Cleveland iron, for it is remarkable for the excellence of that quality, yet there are few districts which produce iron that is more laminated. Perhaps this may, in a measure, be the result of the prosperity of the past few years which has prevailed in the iron trade when quantity and not quality was the great desideratum. In welding hard and soft irons together the difficulty is to get a heat suitable to both, as it is difficult to define the exact temperature for iron in the welding state, for it differs so materially according to the different degrees of quality of iron. The amount of heat which a hard pure iron would absorb before arriving at a proper viscous or pasty condition would be sufficient to destroy a soft impure iron by burning. Iron may be welded at different degrees of heat, varying in color from a greasy yellow up to a white heat, and if heated beyond this point it becomes burnt, though not being fusible when in an uncombined state. Heat has great influence on iron in altering its condition. A high heat will change a fibrous to a crystalline iron, whilst a low welding heat will allow it to retain its fibrous character. Irons in a welding state possess great affinity or attraction for each other, and this is manifested in a greater or less degree according to uniformity of quality. If two pieces of iron are laid together in a welding condition they readily stick to each other, and if the surfaces are of moderate extent it requires some force to pull them asunder. A striking proof of this attraction may be seen in any forge, in the piling of very large masses of scrap containing thousands of pieces, which are heated to a welding state, and then brought out of the furnace, and held in suspension by the middle, between the points of a pair of tongs, and though it may weigh from two to three hundredweight, there is no difficulty in transmitting it from the furnace to the anvil, during which time the particles composing the mass are held together by atomic attraction, but some mechanical force is necessary to bring the particles into closer metallic contact. The difficulty is not so great in welding hard and soft irons together as in keeping them together after they are welded. In a sample before me containing five different kinds of iron, of varying degrees of quality, the welds, so far as we can judge from appearance, seem to be perfect, yet if this sample had much work put on it, if it were upset under the steam-hammer, the harder knots would separate from the softer, their structural forms are so different. The fine crystalline form of the Low Moor iron cannot be thoroughly incorporated with the open molecular structure of the common Cleveland. I believe much of the defective welding found in our Cleveland iron is due to this cause; we find on examination a layer of crystal and another of fibre in regular succession throughout the commoner kinds of iron. A low heat is adopted in its manufacture, purposely to retain its fibrous character; the result is the lamination spoken of. This evil is not confined to the manufacture of bars only; the rail trade has suffered from the same cause. I think you will agree in the opinion, supported as it is by the samples before us, that welding properly performed is neither a soldering nor gluing process. Neither of those words is applicable to the process. I think that it is possible to get a near approach to complete metallic contact by welding; but as the conditions are so varied by reason of the different chemical combinations in iron, it is impossible in the present state of metallurgical science to lay down any fixed rules; therefore, the skill and observation of the workman must supply this want, and be constantly directed to those affinities and combinations which are constantly taking place in all metallurgical operations, under fixed though perhaps undefined laws which govern the results, and give good or bad work in proportion to the extent in which they are regarded or neglected.

Engineering Professorship at Glasgow University.—A legacy of £140 per annum has been left by the widow of the late Rev. Dr. Black, for an endowment in connection with the Chair of Engineering and Mechanics.

WEIGHTS AND MEASURES.

From "Iron."

Mr. H. W. Chisholm, the Warden of the Standards, has just issued his tenth annual report on the proceedings and business of the Standard Weights and Measures Department of the Board of Trade. Thus, it is provided, by statutes passed in 1859 and 1860, that, throughout Great Britain and Ireland, no copies of the standard weights shall be legal unless reverified in the Warden's Department within five years, and no copies of the standard measures unless so reverified within ten years; but a proviso was added authorizing copies of the country standards to be locally reverified within the same periods, by comparison with one of the country sets which shall have been duly reverified in the Standards Department. It appears that, although the law requires gas-measuring standards to be verified in the department, there is no provision for their reverification.

The number of local standards rejected during the year on account of bad workmanship, or as requiring readjustment, was 325 in respect to weights, and 76 in respect to measures—or a total of 401; being fourteen per cent. on the total number (2,780) verified and reverified. From 1869 to 1873, both inclusive, the number rejected range from eleven to twenty per cent., whereas in 1874 the number was thirteen per cent., and in 1875 only nine per cent., now followed by a rise to fourteen per cent.

A list is given of those places in the United Kingdom for which copies of the Imperial standards (exclusive of troy weights) have been officially verified, but without being subsequently reverified within the period prescribed by law. These defaulting places are 105 in respect to weights and 147 in respect to measures, 87 of the latter being in respect to measures of length. It is stated that, under the existing laws, the Standards Department has no control whatever over the local inspectors of weights and measures, and has no power to compel the production of the local standards for reverification. Mr. Chisholm observes: "The department is thus entirely passive in the matter, and the utmost I can do is to record in my annual reports the several places where the law is not duly obeyed." The list is made up to March 31st, and among the defaulters in respect to the reverification of standards of weight we find such places as Weymouth, Gateshead, Stockton, Harwich, Portsmouth, Winchester, Leominster, Deal, Gravesend, Bolton, Preston, Banbury, Oxford, Shrewsbury, Wolverhampton, Guildford, Reigate, Brighton, Chichester, and York—together with the counties of Chester and Wilts.

A series of standard weights and measures has been verified for the Government of Siam during the past year. Mr. Chisholm says it should be noticed that at Siam the standard temperature for weights and measures, is 85° Fah. The Siamese unit of length is the "wa," consisting of eighty English inches, defined by lines upon a solid bar of standard silver. The Siamese unit of weight is the "chang," called by foreigners the "Siamese catty," its legal weight being equal to 2.675 pounds avoirdupois. This standard weight is constructed of platinum iridium. Altogether eight standards were manufactured for the Siamese Government, and submitted to Mr. Chisholm's department for verification. The standards thus made were found to be correct within a fraction which seemed very small. Nevertheless the error was sufficiently large to exceed the limits prescribed by the Standards Department. Consequently the stamp of the department was not affixed to the standards, but official certificates of verification were given, showing the result of the examination or comparison. The standards were engraved with the royal seal of Siam, and with a shield for an inscription to be engraved upon them on their arrival at Siam. We should fear that the further process of engraving would again disturb the fractions of accuracy in respect to the weights, though Siamese science may rest satisfied with the result.

During the past year a complete set of Russian standard weights having been constructed in London for the Government of the Czar, a request was made to Mr. Chisholm by General Gloukhoff, the head of the Standards Departments at St. Petersburg, to compare the several units of this complete set, and to give their values in terms of our Imperial standard pound. The standard weights have undergone a scientific revision in Russia, and it appears that there is a slight departure from the customary figures. The Russian pound was stated a few years ago to consist of 6318.5 grains. At another time it was 6316.81 grains. It is now given as 6319.73146 grains, or 40951196 metric grammes. The standards examined by Mr. Chisholm did not differ materially from the normal values they were intended to represent, and they were accordingly certified in the usual official form to General Gloukhoff.

The time came round during the past year for reverifying, under the Standards Act, the standard weight of 62.321 pounds, being the legalised weight of a cubic foot of water, together with its official copies; and also for reverifying the standard cubic bottle, representing the measure of a cubic foot of distilled water weighed in air against the standard 62.321 pound weight; as well as the gas-measuring standards of one cubic foot, five cubic feet, and ten cubic feet, the contents of which are based upon the standard cubic-foot bottle. The standard cubic foot weight, with its three official copies, was last reverified in 1870. One of the official copies was presented to the French Government in 1871. Consequently only two official copies in addition to the standard remained to be reverified last year. These are made of hard gun-metal, and are cylindrical in form with a knob. They have now been reverified by comparison with the same bullion standards that were used for their original verification in 1859, and for their reverifications in 1868 and 1870.

These comparisons have been checked by further comparisons with the avoirdupois reference standards. Compared with the results obtained in 1870, in which year the weights were readjusted, there now appears an increased weight in the standard to the extent of 5010 grains. The two copies have increased in weight by 4241 grains and 2538 grains respectively. This augmentation of weight is considered due to the oxidation of the comparitively large surfaces which are exposed. These weights do not, however, require to be now readjusted, as their small ascertained errors can be allowed for in comparisons made with them. It is curious that the standard weight showed the least error after the readjustment in 1870, but now shows the greatest. Still the greatest discrepancy is so minute as to amount to less than one part in 80,000, the present error of the standard weight being 5,404 grains out of 92,321 lbs. The cubic-foot bottle has increased 4.12 grains, or 0.056 parts of a cubic inch in capacity since 1869. The present error, in excess, is 174.4 grains, or 0.090 part of a cubic inch, being about one part in 2,500. The three standard gas-holders were readjusted and put into complete working order in 1875. Consequently, their errors are but slight, though the cubic foot gas-holder is rather less correct than it was in 1869. The present ascertained errors, in parts of a cubic foot, are a deficiency of 0.0025 in the cubic foot gas-holder, an excess of 0.0030 in the five cubic feet holder, and an excess of 0.0110 in the ten feet holder. The errors allowed to the local gas measuring standards are appreciably greater than the foregoing, so that none of the latter will be rejected through errors in the imperial standards.

It is a singular omission in the Sale of Gas Act that it makes no provision for the periodical reverification of either the official gas-measuring standards, or the copies deposited with the three metropolitan cities, nor, indeed, of the many copies verified for the use of the local inspectors of gas-meters. On receiving a suggestion from Mr. Chisholm, the chief magistrates of London, Edinburg and Dublin at once consented that the gas-measuring standards in their custody should be put into complete order, and the cost paid out of their corporate funds. The process had not been completed at the date of the present report, so that further reference to the subject is postponed. The propriety of this reverification is shown by the fact that the official gas-measuring standards in the keeping of Mr. Chisholm's department were found to require taking to pieces and setting to rights, so as to rid them of the injurious effects of oxidation.

The question of a standard photometer for measuring the illuminating power of coal-gas comes under discussion in the present report, and would seem to be as important as the institution of a standard of quantity. The instruments now in use for measuring the lighting power of gas include the 100-inch photometer invented by Mr. G. F. Evans; the 60-inch photometer designed in 1863 by Dr. Letheby, and since adopted by the metropolitan gas referees, as well as by the authorities in Canada; Mr. G. Lowe's jet photometer, said to be used as a standard in Italy, and the illuminating power meter introduced by Mr. Sugg. The Evans photometer requires no dark closed room for its operations, and on that account is much used in hot countries. It is also much used in the United Kingdom, particularly by companies supplying gas of high illuminating power. Concerning Sugg's illuminating power meter, it is claimed that the lighting quality of the gas can be determined in one minute from the quantity of gas (measured by an experimental meter which is a portion of the apparatus) found requisite to maintain a flame of gas three inches high for sixty seconds. In Lowe's jet photometer, also, the lighting power of the gas is deduced from the quantity required under specified conditions to maintain a flame three inches high. The photometers of Evans and Letheby are based on Bunsen's method, a disc of paper, partially greased, being interposed between the standard light and the gas flame. The disc is moved to or from one or the other of these lights, until the greased spots are, as near as may be, imperceptible to the eye. It is then tolerably certain that the transmitted light from the one flame is equal to the reflected light from the other. The flame nearest to the disc is therefore the weakest, and the relative distances afford a measure of the power. The method in some degree resembles Count Rumford's equalization of shadows.

Mr. Chisholm observes that "the time has not yet arrived when any photometer hitherto constructed can be relied upon for giving constant accurate results." The difficulty consists in obtaining a trustworthy unit—that is to say, a standard light certain to afford the same degree of illumination so long as the known conditions are unaltered. Hitherto no better standard than the sperm candle has been found. Sperm candles burn at rates varying from about 115 to 126 grains per hour, and the gas examiner has to make allowance for this varying rate. Although a correction is thus applied according to a specified rule, it is doubtful whether the same quantity of sperm always yields the same light, as there is reason to believe that an effect is produced by the quality of the cotton wicks and the method of their plaiting. Mr. Chisholm is informed that a sperm candle recently brought from Russia and tested here against a regulation sperm candle was found to be ten per cent. better in quality, and to have proportionately increased illuminating power.

Attempts have been made to employ Mr. Crookes' radiometer as a photometrical instrument. But it is doubtful whether the action of the radiometer is not rather due to heat than to light. Mr. Chisholm says it is of importance to add that, in the event of any standard photometer being adopted, it is absolutely necessary that authoritative regulations for a uniform mode of using it should be prescribed. This gentlemen further observes that the question of legalizing a standard sixty inch Letheby photometer in this country, as it has been already legalized in Canada, is well worthy of consideration.

An additional set of standard decimal grain weights has been constructed during the year, to be used specially in trials of the pyx. These weights are made of hard brass, and it is proposed to take every precaution in their use, by strictly following the official regulation never to touch standard weights with the hand, but to lift them either with a proper fork, or with a wash-leather, carefully wiping them with a wash-leather after use.

A somewhat notable event of the year has been the laying down at Trafalgar Square of several standards of length embedded in a solid platform of granite. All the details of this operation are given in the appendix to the present report. The platform is situated at the foot of the north wall of the square, and the entire cost has been about, £450. These mural standards are now available for public use, like those erected outside the wall of the Royal Observatory at Greenwich, only the Trafalgar Square standards are on a much larger scale, the platform being nearly 260 feet long. The Standards Commission, in one of their reports, recommended that mural standards of length should be securely fixed for public use in all populous towns, the expenses connected with them to be defrayed out of the local funds. The Warden of the Standards has accordingly sent a circular letter to the local authorities urging the expediency of their carrying this recommendation into effect; at the same time offering them such information as in his judgment would facilitate their course of action.

Various other matters are referred to in the little volume before us, and it is evident that the department of the Warden of the Standards is not only extremely useful, but of increasing importance. It is impossible not to admire the high degree of scientific skill displayed in the various operations, as well as the zeal with which the duties of the department is discharged.

THE MOVEMENT OF THE SEA, VIEWED IN ITS HYDRAULIC RELATIONS TO PORTS AND SHORES.

By A. CIALDI.

From "Rivista Marittima," translated for Proceedings of Institution of Civil Engineers.

In the autumn of 1873 the Royal Venetian Institute of Science, Letters, and Art offered a prize of 3,000 lire for the best essay on the movements of the waves and littoral currents. The competitors were invited to discuss the most accredited theories, and with observations of recognized phenomena, to deduce a more complete theory, especially with reference to the compound action of waves and currents on the change of coast lines, and on the efficacy of maritime constructions; such as might tend to the improvement and preservation of ports and shores, especially those of Italy. The essays might be written in either Italian, Latin, French, German, or English. Signor Cialdi had, in the "Rivista marittima" for 1874, given his "Preliminary Notions as to a Treatise on the Construction of Ports in the Mediterranean," the second chapter of which, treating of winds, waves, and currents, which he regarded as the most important, has been much controverted in Italy. The invitation of the Venetian Institute induced him to appear as an anonymous competitor; citing his own former works, as well as those of his opponents.

The essay, which was the only one presented, although greatly praised for its elaborate learning, was not thought to fulfill sufficiently the conditions of the Institute, and did not receive the prize. It is divided into three parts, each headed by a distinct paragraph of the programme given by the Venetian Institute. The first part contains two articles,—on the accredited theories of the movement of liquid molecules in the formation or development of marine waves; and on tidal and littoral currents. The former article commences by the definition of certain terms, and then refers to the theory of Newton on the velocity of waves, and to that of Gerstner and the brothers Weber, published in 1825, on the orbital movement of the liquid molecules in waves. Mr. Merrifield's "Summary of the Theory of the Oscillating Sea Waves" is also cited. Signor Cialdi concludes this portion of his work by expressing the opinion that he has demonstrated that the theories hitherto produced, in order to explain the motions of the sea by means of mathematical analysis, are not of much use with reference to the questions of the construction of harbors, or the advance or retreat of the shore.

In the second section Signor Cialdi asserts that the tidal wave attains, in the high seas, a velocity of not less than two miles per hour; which rises to six, or even ten miles per hour, according to the obstacles which it encounters on the shores. He holds that in the same degree that these obstacles diminish the velocity of the propagation of the wave, they augment its transporting power, and cites experiments made in France and in England, to show that, at a velocity of six inches per second, water transports soft clay; at one of twelve inches per second, it transports ordinary sand; and at that of thirty-eight inches per second, it transports pebbles as large as a hen's egg. The transporting power of the sea-water he takes to be higher than the above, inasmuch as its density is $\frac{1}{40}$th more than that of fresh water. In calm weather the tide wave on the Italian coasts remains limpid. In stormy weather the Author considers that the turbid matter which it contains is removed in the same manner in which it is brought by the tidal current; so that the tides of the Mediterranean have not a sensible action on the shores of Italy.

He then discusses the "Mediterranean current," known as the littoral or "grazing" (*radente*) current, which flows from the right hand to the left of the observer who faces the sea; and which attains in the Adriatic a velocity of three or four miles in the twenty-four hours; and in the rest of the Mediterranean, on the average, a velocity of eight miles in the same space of time. He gives an observation of his own, made from a small steamer anchored near Corneto, in 12½-feet depth of water (on the 4th of August, 1857), of the bottom of the sea, where he saw the marine algæ bending, perpendicularly to the shore, from west to east, showing the direction of the gentle current at the spot. As the tops of these sea-weeds were about 8½ feet below the surface, he concludes that the littoral current was unfelt at that slight depth, and that the littoral current has little or no transporting power. His investigations are limited to the Adriatic, as that sea has been chiefly studied by Montanari and his followers: and holds that the laws which regulate the accretion of shores must be the same on all the coasts of the world. He then discusses the prevailing winds on the Adriatic, and concludes this section with a note to the effect that it is to be regretted that the littoral currents have been rather sought for in maps and books than measured in the sea itself.

The second part of the treatise discusses first the materials which become obstructions on shores, and then what the Author calls the "garland of adventitious deposits." This region, which D'Archiac has called the "zone of sanding-up" (*atterissements*), extends, according to Signor Cialdi, from the coast line to a depth of 328 yards in the ocean, of 164 yards in the Mediterranean, and of 87½ yards in the Adriatic and in the English Channel; he says that the waves of the sea have a visible transporting power to a depth of 218 yards in the ocean, of 54½ yards in the Mediterranean, and of 44 yards in the Adriatic and the Channel. The materials deposited in this zone he regards as derived, first, from the deposits brought down by rivers; secondly, from the erosion of portions of the sea coast; and thirdly, from the productions of the sea itself; that is to say, from the remains of marine plants and animals. Entering at considerable length into recent works on the natural history of marine life, he concludes that the deposits on the shores of the Italian seas are formed, in the Mediterranean, by thirty per cent. from river deposit, twenty per cent. from erosion of shores, and fifty per cent. from organic bodies; and in the Adriatic, by thirty-five per cent. of the first, five per cent. of the second, and sixty per cent. of the third.

The second section of this part of the essay proposes to establish a complete theory as to the compound action of the waves and currents in altering the coast line, and affecting marine works. It speaks of the depth to which the movement of the waves is felt, and of the submarine current which the Author holds that they generate. It mentions the effect of the wind, in raising the waters on the shore above their mean level by about nineteen inches in the Tuscan Sea, 3¼ feet in the Adriatic, and 6½ feet in the ocean. It refers to the report of the International Commission on the Bay of Pelusium, and to the westward current there prevailing, which flows in an opposite direction to the assumed littoral Mediterranean current. It refers to the action of the dominant winds upon the waves, the phenomena of which he discusses at considerable length.

In the third part the Author treats first of the hydraulic works carried out, especially on the western and southern shores of the Adriatic, the experience derived from which confirms, in Signor Cialdi's opinion, the theory of the wave current. He refers to the deposits of the Po and of the Adige, and to the changes in the *foci*, or openings through which the waters of these rivers finally join the Adriatic, that are due to the variation of the winds.

The second section of this part discusses the subject of such harbors as Signor Cialdi calls port-basins. He concludes that when such a harbor (of which Ancona furnishes an example) has only one mouth or entrance, this must always be placed on the leeward side, or away from the dominant winds. He refers to the actual and the prospective increase in the size of vessels, especially steamers; and to inconveniences in the ports of Naples and of Genoa in consequence of their being open to the prevailing winds.

In the third section Signor Cialdi treats of what he calls canal-ports, which he says are always formed on level, and therefore either sandy or gravelly shores; and are on that account very difficult to maintain. The convenience of navigation demands that such ports should either be at the mouth of a river, at that of a lagoon receiving the tidal water of the sea, or joined by an artificial canal. The essential feature of these ports he takes to be the construction of two parallel jetties, or "guardian moles," leading to the sea. He cites the area of the lagoon of Malamocco (which is 40,200 acres), and the width of the canal between the jetties (which is 515 yards), as an example capable of general application under the second division; the Sulina mouth of the Danube being a case of the first kind. The third case, that of the purely artificial canal, is illustrated by the entrance to Port Said. As to this, Signor Cialdi cites the report of Colonel Stokes, R.E., to the effect that the repeated extension of the pier seems to be a hopeless feature in the method of dealing with the difficulty of the constant deposit of material in the bay; a deposit which is computed by that officer to have amounted to more than 5,000,000 cubic yards within three years.

In the fourth section of this part of the treatise, Signor Cialdi proposes his own method of meeting the difficulty of a canal-port. Instead of two parallel jetties, he proposes to make the leeward jetty much shorter than at present is usual; and to cut the windward jetty into two parts, by an opening about the spot where the bar is generally formed. The jetties should be built with a slightly curved plan, with the convexity opposed to the prevailing wind. At the end of the first part of the longer jetty (where the opening is made) the sea wall is returned to the windward at right angles or thereabouts. It is anticipated by Signor Cialdi that the action of the wave current, deflected by this return, will keep free the opening between the two parts of the main or windward jetty, and thus maintain a free entrance to the harbor.

The work concludes with a summary of the arguments adduced to show that the theory of the wave current is that which explains the action of the sea on the shore, and is alone applicable to the improvement of ports or the preservation of coast lines.

THE MEASUREMENT OF FORCE.*

By ROBERT MOORE, C. E.

Written for Van Nostrand's Engineering Magazine.

In the January number of the Eclectic is an article by Prof. De Volson Wood, of the Stevens Institute of Technology, on the measurement of force, in which several of the positions taken are erroneous, and the whole article as coming from a teacher and author of a treatise on mechanics so remarkable that it ought not to pass without notice.

The main purpose of the article, though

* This paper was read before the Engineers Club of St. Louis.

not very easy to discover, seems to be to show that the absolute unit of force mentioned by Prof. Tait, in a late lecture before the British Association is not as good a measure of force as the pound. In holding thus, he takes issue not with Prof. Tait alone, but with nearly every modern writer on mechanics.

The chief reason assigned for this position is that the pound measures pressures, as well as motions, which he seems to think is not true of any other unit or mode of measurement.

And in particular he says that forces are in general not properly measured by momentum, which is a measure of constant forces only.

In order to show the amount of error involved in these several propositions as well as to bring into clear view the truth concerning the subject itself, it will be best to state as briefly as possible the main doctrines concerning the measurement of force.

Force is a word by which we designate the unknown cause of motion. It is defined as "That which moves or tends to move a body or to change its rate of motion." Of force in itself aside from its effects, we know nothing. In measuring force all we can do is to measure the effect and from this infer the magnitude of the cause. The measurement of force is, therefore, resolved into the measurement of the motions of material bodies, and to do this we must take into account and measure separately, two things:—first, the body itself, and second its velocity or rate of motion.

To measure the body we assume some particular body or piece of matter as a unit, and then compare this unit with the body in question.

The unit is wholly arbitrary and may be anything whatever, a piece of metal, or a volume of water, or some other kind of matter. The unit in most common use in England and America is a piece of platinum called the "Standard pound." The comparison of a body to be measured with the unit may be made in two ways, the first is by the method of volumes. If the substance to be measured is of the same kind as the unit their masses will be as their volumes. This is the way in which we measure liquids, earthwork, grains, &c.

But if the substance to be measured is of a different kind from the unit, we make use of the record method—the method of weighing.

In this method we compare the masses of bodies by means of the effect produced upon them by the force of gravity. If in a scale a body is balanced by one unit we call its mass one: if it takes two units we call its mass two and so on. In doing this we take as our major premiss the assumption which all experienc verifies that at any given place the force which gravity exerts upon bodies is in direct proportion to the quantity of matter which they contain.

This action of gravity upon bodies is their weight. Weight is not matter but a force acting upon matter. But owing to the fact that the force and the body have usually the same name they are often confounded.

Thus, we speak of a pound or kilogramme of matter, and of a pound or kilogramme of force, but the two meanings should be kept carefully distanced. Weight is used to measure matter just as volume is, but matter weight and volume are wholly distinct and unlike.

The weight of a body varies with the intensity of gravity, its gravity of matter is invariable and may be the only invariable thing about it.

To measure the velocity of the body we need two units—a unit of space and a unit of time.

For the measure of velocity is the amount of space passed over in a given time, the velocity varying directly as the space and inversly as the time.

So if we let v and v' be two velocities, s and s' the spaces described, and t and t' the times employed we get:

$$\frac{v}{v'}=\frac{\frac{s}{t}}{\frac{s'}{t'}}$$

If now in this equation we let v',s' and t' each equal unity; that is, if we take as our unit of velocity a velocity in which a unit of space is described in a unit of time, we shall have,

$$v=\frac{s}{t},$$

by which, of course, we do not mean that there is any likeness or identity between velocity, space and time, nor that we actually divide space by time. We mean only that the number of units of velocity is the same as the number of units of space divided by the number of units of time. The equality is one of number only. For uniform motions the foregoing is all we need. The measure of one record is there the measure of every other. But if the velocity be changing, we can only measure it at each instant.

This we do by passing to the elementary values of s and t, assuming the motion to be uniform for the space ds and the time dt. As the preceding formula is true for all values of s and t, it must be true for all values of s and t, it must be true for ds and dt, so that we have

$$v=\frac{ds}{dt},$$

which is an expression for the rate of motion at the given instant dt.

In variable motions, however, we need to know more than the rate at a given instant.

To define the motion completely, we need to know the rate at which it is changing, which rate is called its acceleration. But the acceleration manifestly varies directly as the amount of the change and inversely as the time. That is

$$f=\frac{v-v_0}{t},$$

in which f is the acceleration, v_0 the velocity at the beginning, and v the velocity at the end of the time t. When we pass to the elementary values $v-v_0$ becomes dv and t becomes dt. We then have:

$$f=\frac{dv}{dt},$$

which gives us a measure of the acceleration when the rate of change is not constant.

With these measures of mass and motion, both variable and constant, we are now ready to measure the motions of bodies and pass from them to a comparison or measurement of the forces by which they are produced.

In making the passage from motion to force we are obliged to assume several postulates which are the result of experience and lie at the basis of all dynamics. These may be stated thus :

1. All motion, or change of motion, either in magnitude or direction in material bodies is the result of force. This is Newton's first law of force and may be called the principle of inertia. It enables us to infer the presence of force wherever we see motion begin or change. It does not, however, give us the amount of force. It is qualitation, but not quantitation. We, therefore, need to go further and assume,

2. That forces acting upon equal masses during equal times, are to each other as the changes of velocity which they produce.

3. That the time and total change of velocity being the same the forces are to each other as the masses in which the given change is produced.

4. That with a given mass and a given change of velocity, the forces are to each other inversely as the times during which they act. Or, in other words, the less the time required to produce a given effect the greater the force, and vice versa.

By putting these postulates into algebraic symbols we get the following equation in which is contained the whole doctrine of the measurement of force,

$$\frac{F}{F'}=\frac{\frac{M\,(v-v_0)}{t}}{\frac{M'\,(v'-v_0')}{t'}}$$

in which F and F′ are two forces. M and M′ the masses upon which they act, $(v'-v_0')$ and $(v-v_0)$ the changes of velocity, and t and t' the times in which these changes are produced. Now, if in this equation we make F′, M′, $v'-v_0'$, and t' each equal to unity, we get:

$$F=\frac{M\,(v-v_0}{t},$$

which is the simple and more common form of the fundamental equation, and is also the one from which are derived all the equations made use of by Prof. Wood in the article in question.

But by the supposition upon which his equation is based we have made F′, the unit of force to be a force, which acting upon the unit of mass during the unit of time, will change the velocity by unity.

This is the absolute dynamic unit adopted by Prof. Tait, and by nearly all modern writers on Mechanics. It is indeed the corner-stone of the whole science. Its exact value is determined by our units of space, mass and time, and by these alone.

In England and America, there are the foot, pound and second, so that the British absolute unit of force is a force which acting upon a mass of one pound during one second will produce a change of velocity of one foot per second.

It is about the force which gravity exerts upon a mass of half an ounce.

Prof. Wood, however, objects to this measure of force as not being sufficiently general, and claims that the proper unit is the pound, meaning, of course, the pound of force, or the action of gravity upon the unit of mass. To determine the exact nature and value of this unit, let us go back for a moment to our last equation,

$$F=M\frac{v-v_0}{t}.$$

As we have just seen, when speaking of acceleration, the factor,

$$\frac{v-v_0}{t}=f \text{ or } \frac{dv}{dt}=f,$$

as the case may be, so that the preceding equation may be written

$$F=M\frac{dv}{dt}=Mf.$$

This last is the form used by Prof. Wood, and the study of which he very strongly and very properly recommends as a means of clearing up any confusion which may exist on the subject.

Let us now apply this equation to the action of gravity which as we know produces at the surface of the earth upon all bodies upon which it acts unhindered, an acceleration of about 32.2 feet per second which is represented by the letter g. Putting G for the total force and taking the mass, M, as unity, we get,

$$G=1 \text{ lb. force}=Mg=g=32.2 \text{ absolute units.}$$

From which we see that gravity acts upon the unit of mass with a force of about 32.2 British absolute units of force.

Prof. Wood also considers the case but with a very singular result. He says :—"If in the expression $F=Mf$, we make M and f each unity and consider f as constant, we have, 1 lb. of force=1 lb. of mass × 1 foot velocity. The second member of which is the unit proposed by English writers for measuring force."

Now concerning this equation, in which the word velocity probably means acceleration, we can only say that whilst it might be true in some other planet where the acceleration of gravity was only one foot per second, it is certainly not true in this one where the acceleration is over 32 feet, unless, indeed, Prof. Wood, has some private meaning for the word pound which he has forgotten to divulge. Taking the words in their ordinary meanings the equation is simply untrue, and we are at a loss to see how it could ever have been written. We should be disposed to credit the printer with the blunder and not the Professor did not the argument seem to depend upon it. As it is we must wait for an explanation until we hear from Prof. Wood himself.

Resuming the equation $G=Mg$, in which, where M is one pound of matter, $G=g$ is one pound of force, we see that the force pound is of the same nature as the absolute unit, and measurable by it. Both are forces, and each may be used indifferently as a measure of force. They differ only in the fact that one is g times as great as the other; so that if we have the measure of any force in absolute units, and wish to get its measure in pounds, or gravitation units, we have only to divide the former by g to get the number sought. Thus, let $F=Mf$ be the measure of a force in absolute units, and F_0 be its measure in pounds. Then will

$$F_0=\frac{F}{g}=\frac{Mf}{g},$$

and *vice versa*, $F_0=F=Mf$, or the measure of any force in pounds, multiplied by the acceleration of gravity, gives the nature of the same force in absolute units. But Prof. Wood argues that the pound has a superiority over the absolute unit, in this way, viz.: That whilst the absolute unit "is only applicable to moving bodies," the pound measures also pressures and tensions in which there is no motion, and hence he says. "is the more natural, and certainly the more general measure of force." Now, in taking this position, the Professor seems to go upon the assumption that there is some radical difference between forces which produce motion and pressures or tension which do not produce motion, so that the mode of measurement applicable to the one may not be applicable to the other. Otherwise his argument has no force at all.

But this distinction is wholly superficial and not based upon any difference in the things themselves. A pressure, or a tension, is simply a case of equilibrium in which two forces balance each other, so that the result is not motion but rest. But let one of the forces be taken away, and the result is motion, and the magnitude of the force is measured in the manner just set forth, viz.: by measuring the quantity of motion which it produces when acting freely. For example: a body supported by the hand produces pressure, in which the reaction of the hand holds in check the action of gravity upon the body. Now, let the hand be taken away, and the motion which follows in the body is the exact measure of the pressure, which it exerted the moment before. So that the method of measuring force by means of motion is sufficient for forces of all kinds whether they actually produce motion or not.

Moreover, if this were not true the pound would still have no advantage over the absolute unit. For, as we have just seen, the pound and the absolute unit are exactly the same in kind. Both are forces, and there cannot possibly be anything measurable in terms of the one which is not equally measurable in terms of the other. A pressure can be measured just as well in absolute units as in pounds. For some reasons the pound is the more convenient unit. It is more generally known, and does not involve as high numbers as the other. But aside from its convenience it has no superiority whatever.

On the other hand the pound has one feature which makes it for scientific purposes much inferior to the absolute unit, viz., its lack of certainty.

The pound of force, or the action of gravity upon the unit of mass is not a fixed quantity, but varies with the latitude and with the altitude of the place. But the absolute unit depends for its value only upon the units of mass, space, and time, each of which when once chosen is subject to no variation. The absolute unit is therefore the same at all times and in all places.

A force upon the sun or one of the planets measured in this unit, would have exactly the same measure anywhere in the universe. It is therefore, the only scientific unit, Prof. Wood to the contrary notwithstanding.

Prof. Wood has also a discussion upon the subject of momentum as a measure of force, in which he is no more fortunate than in his treatment of the subject of dynamic units. "Momentum," he says "(Mv) is measured by foot pounds and hence generally is not a measure of force." Now even if momentum were measured in foot pounds as the Prof. says, the validity of the conclusion which he draws from it is by no means evident. Force must be measured by its effects, and it is certainly conceivable that we should take its effect in foot lbs. as our measure, even though we may have some other and better measure.

The horse power, which is a force capable of doing 33,000 ft. lbs. of work per minute, or 550 ft. lbs. per second, and which is the commercial measure of force, is in fact of exactly this kind. The truth is that force may be measured by any one of its measurable effects.

But momentum is not measured in foot pounds. The foot pound in the universally accepted sense of the term, is the overcoming through the space of one foot of a constant resistance of one pound, and is a measure of work but not of momentum, which is a wholly different thing.

For momentum is the numerical product of mass by velocity, whilst work is the product of force by space, and involves neither the idea of mass nor of velocity.

Momentum is, therefore, wholly different in kind from work, and has nothing to do with foot pounds. This difference is seen very clearly in the algebraic symbols of the two, which are:

$$\text{Work} = Fs = \text{Force} \times \text{Space}.$$

$$\text{Momentum} = Mv = \text{Mass} \times \text{Velocity}.$$

In which we see that neither quantity involves a single element of the other.

Prof. Wood seems to have fallen into the common error, already referred to, of confusing the mass pound with the force pound, and to have confused momentum and work.

But in order to see how momentum is used in measuring force, let us go back again to our fundamental equation,

$$F=M\frac{v-v}{t}.$$

If in this the initial velocity $v_0=o$, we get

$$F=\frac{Mv}{t},$$

which means that for this case at least force is measured by momentum, divided by the time in which it is generated. But this equation, as Prof. Wood very correctly remarks, pre-supposes that the force F has a constant intensity during the whole of the time t, otherwise the value given whilst it may be the mean value of the force, may not be its actual value at any given instant. And on this fact he bases the conclusion, which he underscores, that momentum is a measure of constant force only.

But this conclusion does not by any means follow. It is, indeed, true of all measurement that the thing measured must remain constant during the measurement. Otherwise we cannot give it any definite or certain value whatever and measurement becomes impossible. This is true of variable, as well as constant quantities. So that when the quantity to be measured is variable we are obliged in order to meet this condition to take an interval of time indefinitely small during which the quantity is regarded as a constant and measured as such. Thus, in the case before us, if the intensity of the force be changing we take the indefinitely small interval dt during which we suppose the force to be constant. For this interval $v-v_0$ becomes dv and we get the expression already found

$$F=M\frac{dv}{dt}.$$

But in both cases our method is exactly the same differing only in the length of time considered, and both formulae may be embraced in one general statement to the effect—that in all cases the measure of the force is the momentum which it causes, divided by the time in which it is produced. So that momentum may be used as a general measure of force whether it be variable or constant. In the course of his discussion of this question, Prof. Wood gives a short argument which, as illustrating the looseness of his reasoning, it is perhaps worth while to quote in full.

Speaking of constant forces he says: "For this case we have $Ft=Mv$. Similarly for another force acting during the same time we have

$F't=M'v'$. Hence $F : F' :: Mv : M'v'$,

And by assuming one of the forces as a standard, or unit for measuring all other forces, we have:

$$F=\text{Unity}=M'v',$$
$$\text{Therefore } F=Mv=M'v'."$$

But he has just said that $F't=M'v'$ and F' can equal $M'v'$ only upon the condition that $t=1$, a condition which he does not give.

In the general case which he is considering, F=Unity is not equal to $M'v'$, and his conclusion should be

$$F=\frac{Mv}{M'v'},$$

a result utterly without value. The conclusion which he actually, though erroneously reaches, but which is true for the special case in which the time also is unity, viz:

$$F=Mv$$

is somewhat important. For it is the basis of the general statement by Prof. Clerk Maxwell (*Theory of Heat*, p. 83), that "a force acting on a body is measured by the momentum it produces in its own direction in unit of time."

The same principle is also laid down, though in slightly different words by Prof. Magnus (*Mechanics*, p. 62), in a book which is edited and endowed by Prof. Wood himself. It is true that on such a subject authorities are as a general rule of no value. If our equations do not carry their own evidence, it is of no use to appeal to great names.

But in our present discussion of momentum as a measure of force, there is one other authority which is certainly pertinent and which we cannot refrain from citing. It is that of Prof. Wood's own book just published, on "The Elements of Analytical Mechanics." On page 51 of this book, after finding the general equation applicable to variable forces

$$F=M\frac{dv}{dt},$$

he goes on, and in italics, of which he is quite fond, lays down this principle: "Hence the momentum impressed each instant is a measure of the moving force."

So that on the authority of Prof. Wood himself, we may, in spite of the article under consideration, take it as proven that momentum is a general measure of force.

STEAM INJECTORS.

Translated from the French of M. LEON POCHET.

II.

MEANS OF AUGMENTING THE PERFORMANCE OF THE INJECTOR PUMP.—WATER INJECTORS.

We should consider two reservoirs of water R and R′ (Fig. 3) placed at the heights, respectively H and h, above a reservoir S. R serves to raise the water from S, and discharge it into R′. Let us place below the reservoir R a verti-

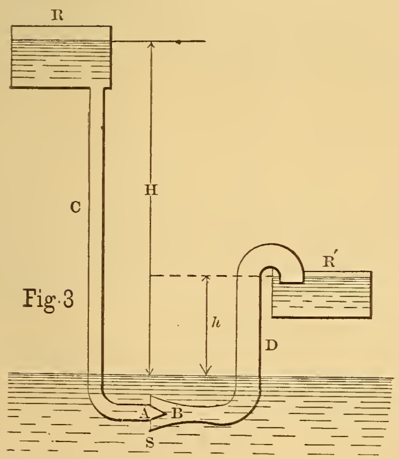


Fig. 3

cal tube C, terminating in a nozzle A, entering into a funnel-shaped opening of a second vertical tube D, leading to the reservoir R′. If we open the stopcock of the tube C, the water will run out by the nozzle A with great velocity, carrying a part of the surrounding liquid, and if the apparatus is well regulated, it will be able to raise the water to the height of the tube D, and it would flow into the reservoir R′. The fluid vein proceeding from the upper reservoir R will, by communicating its motion to the water of the reservoir, carry it on to R′. We will consider the condition of the working of the apparatus.

Let P be the weight of water delivered at the nozzle A;

P′ the weight of water carried per second;

v the velocity of the water leaving the nozzle;

u the velocity of the water at its entrance into the tube B.

Suppose the velocity of the affluent water about the tube B to be neglected, the interchange of quantities of motion will give us the equation

$$Pv=(P+P')u \quad . \quad . \quad . \quad (I)$$

Suppose that the water falls into the reservoir R′ without appreciable velocity, then all loss of living force will be avoided, consequently the velocity u will be determined by the condition

$$\frac{u^2}{2g}=h,$$

whence

$$u=\sqrt{2gh} \quad . \quad . \quad . \quad . \quad (J)$$

but

$$v=\sqrt{2gH} \quad . \quad . \quad . \quad . \quad (K)$$

To be sure we neglect the friction. Substitute these values of u and v in equation I, and we have

$$P\sqrt{2gH}=(P+P')\ \sqrt{2gh},$$

whence,

$$\frac{P'}{P}=\frac{\sqrt{H}-\sqrt{h}}{\sqrt{h}} \quad . \quad . \quad . \quad (L)$$

To ascertain the modulus of such an

engine, it will be necessary to divide the useful work

$$W_u = P'h,$$

by the motor work or propelling force,

$$W_m = P(H - h).$$

This will give:

$$\rho = \frac{P'}{P} \cdot \frac{h}{H-h} = \frac{\sqrt{H} - \sqrt{h}}{\sqrt{h}} \cdot \frac{h}{H-h}$$

$$= \frac{\sqrt{h}}{\sqrt{H} + \sqrt{h}}$$

or again,

$$\rho = \frac{1}{1 + \sqrt{\frac{H}{h}}} \quad . \quad . \quad . \quad (M)$$

The elevation H is necessarily higher than that of h. The minimum of ratio $\frac{H}{h}$ is 1, hence the useful mechanical work will always be less than $\frac{1}{2}$.

We have supposed that the conveyed water comes to the nozzle A with no velocity. This is not so; and to make it more easily understood, we will take a very large funnel MN (Fig. 4).

Fig. 4

If the suction of the tube at M differs but little from that at R, it is clear that the velocity of the water carried will be quite sensible.

Call this velocity v'. The equation (I) should be written in the following manner:

$$Pv + P'v' = (P + P')u \quad . \quad . \quad (N)$$

Since the apparatus is placed nearly at the surface of the water in the discharging reservoirs, the flow of water between the two points M and N can be produced only by difference of pressure. At M we have atmospheric pressure augmented by the slight height of water MP. At N we should have atmospheric pressure diminished by a small amount. If we call x this difference or *depression* expressed in head of water, we shall have

$$v'^2 = 2gx \quad . \quad . \quad . \quad . \quad (O)$$

The velocity v of discharge at the nozzle A will be given by the equation

$$v^2 = 2g(h + x) \quad . \quad . \quad . \quad (P)$$

and the common velocity of the water mixed in the tube R should satisfy the relation

$$u^2 = 2g\,(h + x) \quad . \quad . \quad . \quad (Q)$$

In short, if we call ω, Ω, O, the sections of the pipe and of the tube at M and at R, we shall have the relations:

$$\left.\begin{aligned} P &= 1000\,\omega\,v \\ P' &= 1000\,\Omega\,v' \\ P + P' &= 1000\,O\,u \end{aligned}\right\} \quad . \quad . \quad . \quad (R)$$

which gives the following:

$$O\,u = \omega\,v + \Omega\,v'.$$

The heights H, h and the weight P being given, the equations (N), (O), (P), (Q), (R), will allow us to calculate seven unknown quantities

$$P', \quad v, \quad v', \quad u, \quad \omega, \quad \Omega, \quad O, \quad x.$$

Here are eight unknown quantities. One of these is to be determined before solving the problem. It is the value x of the difference of pressure, mentioned above, and which varies with the adjustment of the apparatus.

The formula expressing the work indicates in what way this value varies.

The useful work is

$$W_u = P'h,$$

and the motor work or propelling force

$$W_m = P(H - h).$$

The rendering of the system is then

$$\rho = \frac{W_u}{W_m} = \frac{P'}{P} \frac{h}{H-h}.$$

Now, from equations (N), (O), (P), (Q), we deduce:

$$\frac{P'}{P} = \frac{v-u}{u-v'} = \frac{\sqrt{H+x} - \sqrt{h+x}}{\sqrt{h+x} - \sqrt{x}} \quad . \quad . \quad . \quad (S)$$

Substitute in the value of ρ, it becomes:

$$\rho=\frac{\sqrt{H+x}-\sqrt{h+x}}{\sqrt{h+x}-\sqrt{x}}\,\frac{h}{H-h}$$

$$=\frac{\sqrt{h+x}+\sqrt{x}}{\sqrt{H+x}+\sqrt{h+x}},$$

or again,

$$\rho=\frac{1+\sqrt{\frac{x}{h+x}}}{1+\sqrt{\frac{H+x}{h+x}}} \quad . \quad . \quad . \quad (T)$$

If we compare this formula with (M), we discover that they are the same, when we make $x=0$. This supposes the velocity $v'=0$. It is easy to prove that the performance (T) increases with the difference x, and that it is always less than 1. We shall have the theoretical limit of its value in making $x=10^m,33$. This difference may be artificially made by raising the injector above the reservoir (Fig. 5), which will force the water to rise to the height C D.

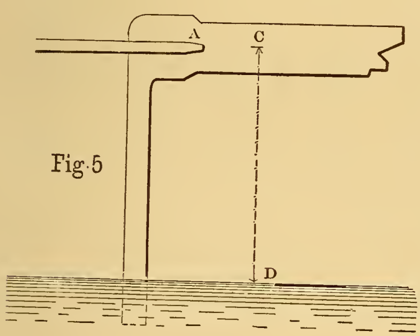


Fig.5

Suppose

$$P=1, \quad H=500^m, \quad h=5^m.$$

If, at first, we suppose the depression to be nothing, the equations (L) and (M) give us:

$$P'=\frac{\sqrt{500}-\sqrt{5}}{\sqrt{5}}=9,$$

$$\rho=\frac{1}{1+\sqrt{100}}=0,091.$$

To arrange the apparatus in a way to realize a depression of five meters, we make $x=\rho$ in equations (S), (T), and we have:

$$P'=\frac{\sqrt{505}-\sqrt{10}}{\sqrt{10}-\sqrt{5}}=20,85,$$

$$\rho=\frac{1+\sqrt{\frac{5}{10}}}{1+\sqrt{\frac{505}{10}}}=0,211.$$

By this hypothesis the performance will have more than doubled. The arrangement of the apparatus has then a great influence upon its action. It should be so that the water raised arrives with considerable velocity at the injector. For this object we direct currents of water by means of several successive funnels (Fig. 6).

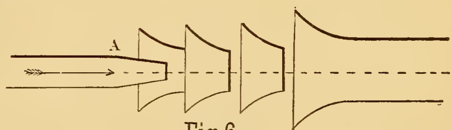


Fig.6

This arrangement is found in several machines of English origin.

We readily understand that the jet of a steam injector may be used as a water injector.

A steam injector conveys, for example, fifteen kilogrammes of water per kilogramme of steam discharged, and communicates a velocity capable of surmounting a pressure of five atmospheres. In other words, the height to which the jet will be able to rise is $41^m,32$.

If we make this liquid jet pass through the nozzle A in Figs. (3), (4), (5), (6), we will be able to carry a new quantity of water, which, it is true, is not raised so high. But if it is not necessary to raise the water above five meters to reach the $41,^m32$, it is clearly to our interest to adopt this arrangement.

The same considerations which we have recommended to place the injector above the supply reservoir are applicable here.

We will now give an account of the theoretical performance of the apparatus in (Fig. 7).

The proportion of water carried by the steam jet is reckoned from the height at which the injector is placed above the discharging reservoir, from the pressure of the boiler and from the amount of water practically raised. Equations (D) and (E) will furnish the proportion of water carried and the velocity of the mixture. The reservoirs B and C being at the same pressure, that is to say, the atmospheric pressure diminished by the height A R, the equation (B) will give:

$$v=\frac{w}{1+y}.$$

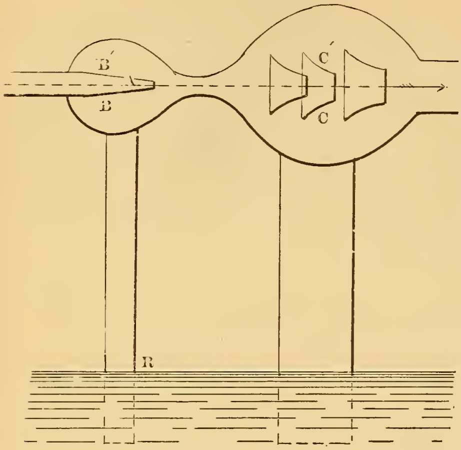


Fig. 7

Knowing the velocity v of the liquid jet at its entrance into the chamber C, we calculate the weight of water carried by the jet by means of formula (S), in giving a start to the depression x, and in calculating the dimensions of the suction apparatus by means of equation (R). We will remember in equation (O) that the velocity v' represents the projection upon the axis of the jet, of the real velocity of the raised liquid streams. It will be necessary, then, to take into account the angle at which the funnels taper.

It is practice alone which can determine the best arrangement of this apparatus, whose theoretical principles only we have established.

We will show by an example how these theoretical calculations may be made.

Example.—To raise the water from the hold of a vessel, knowing the height of suction to be five meters; and the fall of the discharge, five meters. The pressure of the boiler is three atmospheres.

The table (3) gives us for the velocity of the flow of dry steam of three atmospheres at $\frac{1}{2}$ atmosphere final pressure, 739 meters. It will be $w=739$. We will then have equation (D):

$$v=\frac{w}{1+y}.$$

If we make $y=20$, we will find:

$$v=\frac{739}{21}=35^{m},20.$$

The height designated by H is here:

$$\frac{v^2}{2g}=\text{H}=63^{m},18.$$

Since the pressure which exists in chamber C about the funnels, is only $\frac{1}{2}$ atmosphere, we will be able to realize at the axis of the jet only a slight depression; we will suppose two meters. It will be, then, $x=2$, and we will have equation (S):

$$\frac{\text{P}'}{\text{P}}=\frac{\sqrt{63,18+2}-\sqrt{5+2}}{\sqrt{5+2}-\sqrt{2}}=4,41.$$

The weight of water positively raised then will have been:

$$4,41\times 20=88^{k},20,$$

per kilogramme of discharged steam. The mechanical work produced has for its value:

$$88^{k},20\times 10^{m}=882 \text{ kilogrammeters},$$

per kilogramme of steam.

The table (1), that for a weight of water raised to $89^{k},63$, which is nearly equal to 88,20; the Giffard injector produces only 197 kilogrammeters. If we keep the injector at five meters above the surface of the water to be raised, and make use of this apparatus without the intervening injector of water, we should calculate the weight of water carried in the following manner. We should have for the necessary velocity to cause the jet to attain to five meters of height of discharge:

$$v=\sqrt{2g\times(5+5)}=14 \text{ meters},$$

$$1+y=\frac{739}{14}=52,80,$$

whence

$$y=51,80.$$

The weight of water varied would be only $51^{k},80$, in place of $88^{k},20$, which we have found in employing the water injector.

The steam injector arranged with a water injector to serve as a pump, has then a notable advantage over one used solely for steam. Several machines founded on these principles are used in England for draining mines. The pre-

Velocity of Flow of Dry Steam under Different Initial and Final Pressures.

The velocity of a mixture of steam and water, containing x of steam and $1-x$ of water, may be obtained by multiplying the numbers of the table below by $\sqrt{x}$.

Pressures and Final Temperatures.		Pressures and Initial Temperatures.							
		8 at. 170°,81	7 at. 165°,54	6 at. 159°,22	5 at. 152°,22	4 at. 144°,00	3 at. 133°,91	2 at. 120°,60	1 1/2 at. 111°,74
Pressures.	Temperature.	485,79	489,71	494,11	499,13	545,02	512,22	521,70	527,99
atmos.	degrees.	meters.	meters.	meters.	meters.	meters.	meters.	meters.	meters.
7	165,34	223	..	..	..	..	..	..	..
6	159,22	325	238	..	..	..	..	..	..
5	152,22	411	349	258	..	..	..	..	..
4	144,00	494	445	381	283	..	..	..	..
3	133,91	580	540	490	421	349	..	..	..
2,4	126,46	636	601	558	501	420	279	..	..
2	120,60	676	645	606	555	485	372	..	..
1,8	117,30	698	668	632	584	519	417	190	..
1,6	113,69	721	694	658	613	553	460	276	..
1,4	109,68	746	719	686	645	588	504	347	..
1,2	105,17	773	748	717	678	625	549	463	274
1,00	100,00	803	779	750	714	666	596	477	366
0,90	97,08	819	797	769	734	688	621	498	409
0,80	93,88	837	815	788	755	710	647	543	451
0,70	90,32	856	835	809	777	735	676	578	494
0,60	86,32	877	857	833	802	763	706	615	539
0,50	81,71	900	882	858	830	792	739	655	585
0,40	76,25	928	910	888	861	826	770	699	636
0,30	69,49	960	944	924	899	866	821	751	694
0,20	60,45	1,002	988	969	947	918	877	814	765
0,10	46,21	1,065	1,052	1,037	1,017	993	958	906	865

ceding considerations demonstrate that the employment of these machines is not very convenient. Their use is justified only when it is necessary to accomplish rapid drainage with simple apparatus.

EJECTOR CONDENSERS.

Let us conceive that we put an injector on the escape pipe of a condensing-engine. The apparatus will work as usual, that is to say, according as the escaped steam arrives it becomes condensed by the contact with the cold water furnished by the reservoir, will maintain a vacuum, and the mixture of water with the condensed steam imparting a great velocity will be capable of surmounting the excess of exterior atmospheric pressure over the pressure of escaping steam.

We shall thus be able, by the simple interposition of the injector apparatus, to supplant the air pump and all the accessories, and we shall economise the work absorbed by this pump, often very considerable.

Such is the principle of ejector condensers, the employment of which tends, probably, to become general.

Professor Rankine has reported the experiments made in 1868, upon a condenser ejector of the Morton system. The apparatus (Fig. 8) differs from ordinary steam-injectors in that the cold water is drawn by the central tube; the escape of steam is distributed about the central jet by the very long and concentric funnels. In this way the living force of the cold water suffers no loss.

This living force is considerable since the presssure which exists about the cold water, at the moment in which it mixes with the jet of steam, is necessarily less than the pressure at the escape, without which the steam would not flow out, so that the water possesses the ve-

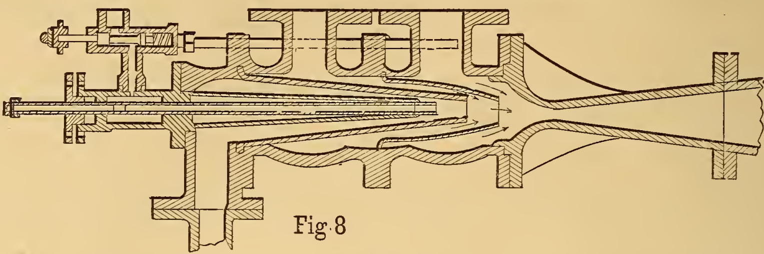


Fig. 8

locity due to the excess of the atmospheric pressure over the pressure of the escape.

In the above named experiments Prof. Rankine has found the following results:

	Per sq. centimeter.
Absolute pressure at the boiler.	3^k,427
Absolute pressure at commencement of escape........	0^k,756
Mean pressure maintained behind the pistons by the condenser ejector..............	0^k,299
Pressure kept near the funnels.	0^k,210
	Centigrade.
Temperature of cold water....	8°,4
Temperature of water of condensation..................	30°,3
Weight of cold water employed per kilogramme of steam....	28^k,40

These results are, as we see, very satisfactory. They are not widely different from those which were obtained by the air-pumps, but these latter require a notable expenditure of moving force.

In the machine experimented, Rankine valued the effective force at twenty-four horses, and the economy realized by the replacing one horse power air-pump at four per cent.

The theory of the condenser ejector does not differ from that of ordinary injectors, only there has been no account taken of the velocity at which the cold water arrives, that here has considerable value, which is neglected in our general equation (C). To take account of it, we should add to the first member of this equation a term

$$\frac{AU^2}{2g}y,$$

representing the living force of the weight of water y.

In reality we will be able to neglect the term $\frac{V^2}{2g}$.

The determination of the velocity and the calculation of the dimensions of the apparatus are made, according to the method explained in beginning of article for April. This is a problem which presents no difficulties.

The Morton apparatus has one peculiarity which we ought to describe. To put the apparatus in motion, we allow a priming of steam from the boiler to pass through a central tube. It may happen that the pressure falls below the proper limits, for the working of the apparatus. Under these circumstances, the cold water flows into the escape-pipes, and then into the cylinders. Every time that this inconvenience threatens the central steam jet is automatically opened by a spring piston, and its power communicates to the cold water jet a sufficient impulse to prevent its deviation towards the cylinders, and re-establishes the normal working of the machine.

THE INJECTOR EMPLOYED IN A HYDRAULIC PRESS.

Suppose that we place an injector at the foot of a cylinder of a hydraulic press (Fig. 9). The jet of hot water may be introduced into the cylinder so that the pressure will be lower than that which corresponds to the velocity of flow. We should be able then to work a hydraulic press with a pressure

$$\frac{V^2}{2g}.$$

Suppose the pressure at the boiler be five atmospheres, the jet according to table, page 213, could rise to the height of 482 meters; this corresponds to

482,000 kilogrammeters per sq. meter,

or to

50 atmospheres.

The same table shows that the mechanical work realized in these conditions is only

3063 kilogrammeters,

per kilogramme of steam used.

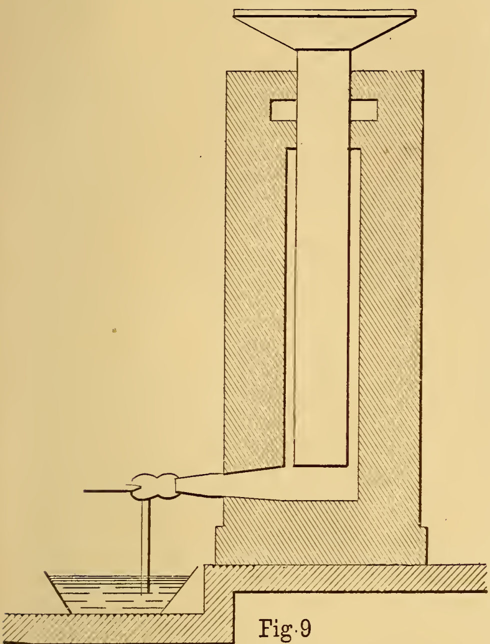


Fig. 9

The work diminishes in the same proportion as the pressure diminishes. Consequently, it would be better to work with high pressure and so diminish the diameter of the hydraulic press.

This is a novel application of the injector, and may prove of service in situations where a hydraulic press is necessary, and where a pump of sufficient power is wanting.

Such an application has not yet been made, at least to our knowledge, and needs preliminary experiments.

PUMPING GAS BY STEAM.—EXPLANATION OF THE FEEBLE WORKING OF FEEDING OR DRAINING INJECTORS.

That which causes the weakness of the performance of a steam injector employed as a draining pump, is the disproportion between the height to which a liquid mixture may be raised, which is several hundred meters, and the height to which we in reality raise them. The apparatus does not give its maximum of performance excepting for very great heights. The disproportion which exists between the specific gravity of the body raised, which is here water, and that which is carried along with it, that is to say, steam, is another source of loss.

In effect, the relative velocity of the water raised at the moment when it mixes with the condensed steam, is so slight that it is not worth taking into account. Let us suppose, on the contrary, that the steam escape in a gaseous medium which it will drag along by a sort of lateral friction (see Fig. 10), and as in a water injector. It may happen that the velocity of affluent air be considerable, consequently cannot be neglected.

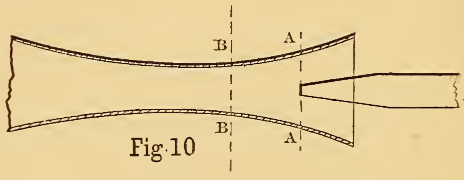


Fig. 10

Now this circumstance will augment the performance, just as in the water injector.

Let W be the velocity of the steam, w that of affluent air, v that of the supposed mixture in the contracted section B B, y the weight of air drawn per kilogramme of steam.

The momentum of the steam will be

$$\frac{W}{g},$$

that of affluent air,

$$\frac{w}{g}y,$$

that of the mixture,

$$(1+y)V.$$

Neglecting the difference of pressure in the sections A and B, we will [have the following equation:

$$W+wy=(1+y)V,$$

whence we find

$$V=\frac{W+wy}{1+y}.$$

The living force of the steam was

$$\frac{W^2}{2g},$$

that of affluent air,

$$\frac{w^2}{2g}y,$$

that of air after the mixture,

$$\frac{V^2}{2g}y.$$

The performance of the apparatus will be then:

$$\rho=\frac{y\frac{V^2}{2g}}{\frac{W^2}{2g}}=\frac{y\left(1+\frac{w}{W}y\right)^2}{(1+y)^2}$$

When we suppose the velocity of the material drawn to be nothing, as that in the Giffard injector for feeding boilers, $w=0$, and the formula of the performance is reduced to

$$\rho'=\frac{y}{(1+y)^2}.$$

We see at once how feeble this action is when y is not very small.

When $y=1$ $\rho'=\frac{1}{4}=0,25$
When $y=15$ $\rho=0,058$.

If, on the contrary, the ratio $\frac{w}{W}$ be slightly increased, the term $\left(1+\frac{w}{W}y\right)^2$ will increase very sensibly the value of the mechanical performance.

For example.—If we make $y=15$ and $\frac{w}{W}=\frac{1}{6}$ the ratio realisable in practice, the calculations give $\rho=0,72$ in place of 0,058, which we have found in making $w=0$.

This simple discovery suffices to make us understand that steam injectors are more likely to give good results when employed as gas pumps than when used as water pumps.

LOCOMOTIVE EXHAUST.

The exhaust of a locomotive is only an application of preceding considerations. Only in these machines the steam jet is intermittent, notably augmenting the results which we should obtain with a continuous jet. People do not know that the draught of the locomotive hearth is, if I may say so, due only to the escaping steam; this is, truly, the fundamental principle of the construction of these powerful machines.

Prof. Zeuner has demonstrated by calculation, and by experiment, that the weight of air drawn into the chimney of a locomotive is proportional to the weight of steam expended. So the combustion is more active when the engine works fastest.

It has been long known, in a general way, that the velocity of a locomotive engine ought to be pushed to its utmost limits when required to perform important work, as when ascending a slope.

Generally the proportion of the weight of air drawn to the weight of steam employed, is between 2 and 3 to 1.

M. Péclet reports the experiments made by M. Glépin upon the draught produced by the continuous steam jets opening into cylindrical tubes. The results are quite various, according to the diameter and the length of the tubes. We have usually found that the performance increases with the length of the tubes. Its value has been a maximum with the tubes from $0^m,50$ to $0^m,55$ in diameter, and from 3 meters to $3^m,50$ in height. It was then raised to 0.1145. We here call performance the proportion of the living force of air drawn to the living force of the steam jet.

It seems demonstrated that the intermittent jets produce superior action, and according to M. M. Flachat, and Petiet the work produced by the intermittent injections of steam in the chimneys of locomotives varies from 0.5 to 0.16 of the work which the steam is able to produce.

Usually in this kind of apparatus it is necessary to multiply the surfaces of the contact of steam and air. Then annular jets are better adapted for such work than the compact cylindrical jets.

STEAM BLOWERS.

Several important processes are founded upon the conveying of air by a jet of steam. This method has been applied to the ventilation of mines. It was also employed to ventilate the great machine gallery at the Paris Exposition, in 1867.

To conclude, M. Siemens has made a new application in the manufacture of steel. In his apparatus, the air is drawn by a double tube through an annular jet and a central conical jet. The air is introduced by an annular central orifice, and by orifices through the outside partition of the apparatus. The contacts of the fluid entering and the fluid escaping are thus greatly multiplied, and this circumstance is eminently favorable to the action.

The mixture of steam and air is introduced into a reservoir containing bits of coke crushed and washed by a current of cold water. The steam is condensed and the air escapes mostly free from steam.

As a means of forcing currents of air for purposes of ventilation this method of M. Siemens is worthy of consideration.

RAILWAY CURVES AND HIGH SPEEDS.

From "The Engineer."

Much as has been done in the improvement of permanent way as laid on most of the railways in this country, there cannot be any doubt that the high speeds and great weight of the rolling stock now used on these lines necessitate a more perfect system of way than has yet been adopted. It is true that while new the tracks used are strong enough to carry their loads, but sufficient marginal strength is not given to these to allow of their being capable of continuing to do this except under the most scrupulously efficient inspection and maintenance, and even with this there are weaknesses which gradually increase, but which are not always apparent. The rails are in almost all cases of ample strength, but more efficient means are needed by which the gauge may be rigidly maintained. This remark is especially true as regards those lines where curves are frequent and where trains run at high speeds over them. One of the most valuable deductions derived by Baron von Weber from his experiments on the stability of the permanent way of railways, the results of which he published in 1869, was that the ordinary forms of way owed their stability and powers of resistance to the enormous strains visited upon them by fast heavy trains, in a very large degree to the insistent weight of those trains; and that were it not for the tie formed by the axles of the engine and vehicles, through the friction of their wheels on the rails, the resistance of the latter afforded by the spikes holding them to the sleepers would be wholly insufficient to prevent their motion laterally, or their canting to such an extent that engines and vehicles would be continually dropping between the rails and causing accidents which, as it is, are not very frequent, not, however, by reason of the inherent strength of the permanent way, but by virtue of the tie which every axle forms. Weber also took care to pronounce a warning against relying upon this strength only imparted for the moment to the track by the train running over it, because that borrowed help is always an uncertain and variable element in the resisting power of the line. All engines, and especially six-wheeled engines, vibrate on the central wheels, so that the vertical oscillation at the leading and trailing wheels is in many cases very considerable. This oscillation is in effect equal to alternately increasing and decreasing the loads on these wheels, and therefore, in the latter of these cases, to take away all help to the permanent ways afforded by the tie which the axle of each loaded wheel forms. This help, then, is taken away just when the rails need most support—viz., when the engine is plunging and wandering.

Baron von Weber found, in a series of experiments extending over a considerable time on engines constantly running, that the load on the springs mentioned was sometimes so increased as to exceed the normal load by over a hundred per cent.; while, on the other hand, the load was sometimes so reduced as to be only about seven per cent. of the normal load. This shows how important it is that the track should in itself be of sufficient strength without relying in the slightest degree upon any such help as may be afforded by the weight of the engine and train. Every railway engineer has seen evidence of the tendency of the track at each end of a curve to move outwards, the result of the tangential direction which the engine and train tend to pursue, but which is prevented by the rails, not, however, without the gradual but limited movement outwards referred to. It is at these places that a combined pitching and wandering motion of the engine is greatly increased, if not originated, and the motion generally continues with more or less severity throughout the curve, for the engine, in attempting to pursue a right line direction, is continually being thrown from the outer to the inner side of the curve and back again by its right line tendency and centrifugal force. On curves, therefore, and at the approach to these, the permanent way should be especially strong and capable of rigidly preserving its gauge. The experiments of Baron von Weber were carried out on permanent way laid with flat-footed rails fastened down by hook-headed spikes. This is one of the worst forms of way, though much used abroad; and although the results Weber obtained as to the resistance of the way to spreading would have been very different if made on our chair-supported rails, his results give very valuable and applicable information.

Many of the accidents which follow derailment take place at or near curves, and it seems questionable whether the old practice of giving to the outer rail the amount of super-elevation which theory dictated should not be returned to. It is of course true that this super-elevation cannot be made to suit different speeds or curves; that which would be necessary for fast trains would be much too great for slow trains. But the effect of too high an elevation for the latter would not be so serious as an insufficient amount for the former. High speeds are moreover the rule now rather than the exception, so that for the larger number of trains the full super-elevation is necessary. At present the most general practice is to give the outer rail a super-elevation of only from 1 in. to 2 in., but, on a curve of, say, 20 chains radius the centrifugal force would, at a speed of forty-five miles per hour, be rather more than one-tenth of the weight in motion, and the necessary super-elevation would therefore, on a 4 ft. 8½ in. guage, be rather more than 5⅝ in., or roughly, about three times as much as is usually given. With an engine running perfectly steadily and following exactly the curve, the lateral pressure tending to cant the outer rail, would with the above amount of super-elevation, be practically nothing; but with a long heavy train the case would be different, as the engine would exert some, and the hinder wheels a considerable amount of lateral pressure, due to the tendency of the train to pull straight. There is also another condition, and an important one, which tends to increase the lateral and vertical pressure on the outer rail and take the load off the inner rail.

This is the fact, that the centrifugal force acts in the center of gravity of the engine or vehicles, and therefore tends to lift these off the inner and tilt them on the outer wheels, and this and its effect will of course be greater as the center of gravity is higher. Slight variations in resistance and speed will therefore cause the weight to be alternately lifted off and dropped on to the inner rail, oscillations and wandering will be set up especially with the engine, and the forces visited upon the outer rail will be alternately much greater and smaller than normally, and the amount of the forces quite uncertain and unascertainable.

When, however, only a very small super-elevation of the outer rail is adopted, as is usually now the practice, these forces become enormously increased, especially as regards those due to the horizontal oscillations. With an engine weighing 40 tons, and running at the above speed on the assumed curve of 20 chains radius, the centrifugal force supposing little or no super-elevation of the outer rail, would be about 4 tons while the engine ran quite steadily round the curve. The last condition, however, seldom obtains, for the increase and decrease of the load on the opposite springs, due partly to the lifting and dropping above described, gradually set up both a pitching and wandering motion, and as the engine is urged from the inner to the outer rail the latter receives an impact strain very feebly represented by the 4 tons due to centrifugal force. The tendency to spreading of the gauge will be most intense on approaching or entering a curve; and although it would perhaps be impossible to arrive by calculation at what it would be at these points, it is evident that it would be much more nearly represented by the energy of the engine than by that of centrifugal force. Although it may not be necessary to look for any radically new system of permanent way, it certainly is of the greatest importance that, considering the heavy engines and loads and the high speeds now so largely observed, the track, if of the present forms, should be of the strongest description, laid and maintained in the most careful and thoroughly efficient manner possible. Consideration of the question here referred to, seems to us to suggest that the high speeds now adopted for the express trains on some of the South London lines from Ludgate-hill and Victoria, can only be observed at great risk, even though the road be maintained in good order. When it is remembered that some miles of these lines are carried on viaducts of some height and through thickly populated districts, it will be easily imagined that the derailment of one of these express trains, loaded as they often are to the full, at or near one of the many curves, would be attended by the most appalling results ever chronicled. The recent accident to the Pullman car train on the Midland Railway, and that to the Falmouth express, were both on curves, and were probably largely due to the spreading of the gauge by the strains visited on the outer rail by the forces referred to.

THE FREIGHT COMPETITION OF 1876.

From the Eighth Annual Report of the Railroad Commissioners of Massachusetts.

In the last annual report of this Board, a somewhat detailed account was given of the severe competition among the through east and west lines which had existed during a large portion of the year 1875, under the influence of which rates were reduced to a point lower than had ever before been known. In December of that year, at the time the report in question was prepared, a combination among the through lines had been at last effected, and it was understood that the war of rates was to cease. The difficulty had arisen between the Grand Trunk line and its eastern connections, to and from competing points in New England on the one side, and the Boston and Albany and New York Central on the other. It thus, as did not require to be pointed out, affected the interests of Boston more immediately than those of any other city in the country, though the struggle involved the whole question of through rates. The settlement usually in such cases was finally effected,—the more direct line agreeing to a division of through business with the less direct, based upon a rule of apportiontment which was supposed to secure to each a fair share of the business;—in this case the through business was divided on the basis of the amount of it done by each line during the two previous years. In other words, the business was practically "pooled," a fixed schedule of rates was agreed upon, and competition ceased. At the time, the members of this Board expressed the opinion that this arrangement in no way touched the root of the difficulty, and that it would prove to be merely temporary. This speedily proved to be the case.

The combination of December, 1875, was, in fact, of even shorter duration than any of its numerous predecessors, for it lasted scarcely one month. On the 7th of February, it was broken in consequence of a misunderstanding between the Erie and New York Central railroads, and a new war of rates was begun on all east-bound through freights, under the influence of which they fell rapidly. This continued until the 2d of March, when another meeting of the representatives of through lines was held, and renewed efforts were made to bring about a combination. These, however, resulted in nothing, except a brief postponement of an inevitable struggle. They wholly failed to touch the real root of the difficulty. This no longer lay in the old and chronic inability of the railroad officials to put any trust in each other's good faith, and rigidly to enforce a scrupulous regard to agreements upon their subordinates. The struggle had assumed a new and, to the railroad interests, far more dangerous form, that of a bitter rivalry between the great commercial cities of the seaboard. Baltimore and Philadelphia were not only asserting an ability to compete with New York City as exporting points for Western produce, but owing to the thorough organization and perfect development of their great through railroad lines, they were demonstrating their power to do it. Ever since the opening of the Erie Canal in 1825, a monopoly of the business of exporting produce has been practically conceded to New York. As is very well known, until within the last ten years it was not supposed that railroads could compete for the carriage of cheap and bulky articles with lake or even slackwater navigation. Rates, however, have generally fallen, until it has at last been demonstrated that under certain favorable conditions it is more advantageous at all seasons to forward nearly every description of merchandise by rail than by water. Accordingly, the amount of agricultural products moved by rail from west to east, as compared with that moved by water, has gradually risen until at the close of navigation (December 2) of the year just ended, it amounted to more than half of the whole quantity moved. In 1873, the proportion was 29.8 per cent. moved by rail to 70.2 per cent. by water; in 1874, it was 33 per cent. by rail to 67 per cent. by water; in 1875, it was 41 per cent. by rail to 59 per cent. by water; and at last, in 1876, it was 52.6 per cent. by rail to 47.4 per cent. by water. This transfer, also, had taken place notwithstanding the fact that during the years named the pressure of competition had forced down rates on wheat carried by lake and canal from Chicago to New York by more than one-half,—from 19.2 cents per bushel to 9.5. Lower than this they could not go, and at this rate the railroads were taking the traffic. Under these circumstances, it was inevitable that a wholly new phase of competition must be developed. Canal navigation was possible to New York alone; but when the traffic passed from the canal to the railroads, other cities possessed equal if not superior advantages. Accordingly, the struggle was no longer between the railroads leading to New York and the Erie Canal, but between railroads leading to different seaboard points. The monopoly of New York was threatened. Neither was the result of the impending struggle by any means so certain, as long habit might induce many people to suppose. The prescriptive enjoyment of an undisputed monopoly has produced in the case of New York City the usual results, and both railroads and business community of that place, confidently relying on long possession and natural advantages, had allowed abuses to creep in, or failed to supply improved facilities, until the handling of produce for export there was made most unnecessarily expensive. Meanwhile, the cities of Philadelphia and Baltimore, having great natural disadvantages to overcome, were naturally forced to husband every resource and make the most of every circumstance in their favor. All this they did with a degree of sagacity, foresight and success, well deserving the careful study of other and more favorably located communities. To Massachusetts, and the city of Boston especially, their experience is very suggestive. The policy pursued by Massachusetts and Boston during the last twenty years of great railroad development, has been in fact the direct opposite of that pursued by Pennsylvania and Philadelphia, or by Maryland and Baltimore. Not only also has it been the direct opposite, but it still continues to be so. In the case of the two last-named communities, the fundamental principle of their through railroad development has been a complete and thorough concentration of force,—the idea of local competition in through business received no favor. It seemed to be instinctively appreciated that the struggle was not between rival lines leading to Baltimore or to Philadelphia, but between single thoroughly developed lines leading to those cities and other lines leading to New York. Accordingly, the whole resources of the two communities were, under the direction of very able men, devoted to the complete development of these single lines. Meanwhile, in Massachusetts, during the early period, the Boston & Albany, then known as the Western railroad, had been in great degree built up by the aid of the State, exactly as the Pennsylvania and the Baltimore & Ohio had been. Had the same policy of concentration been subsequently pursued, it would have led to the complete and thorough development of that line, without any regard to local competition, and to the securing by it at the proper time of the connecting roads necessary to give to Massachusetts and to Boston an independent all-rail route to the West. This would have been perfectly feasible, down to a time as late even as the year 1868. The New York Central and the Lake Shore & Michigan Southern lines might have been made just as much a part of the Boston & Albany road as the Pittsburg, Fort Wayne & Chicago is a part of the Pennsylvania road, or its Chicago extension is a part of the Baltimore & Ohio. Most unfortunately, a theory of railroad development, natural, perhaps, and reasonable enough in the early and experimental days of the system, but long since abandoned elsewhere, still held possession of the public mind of Massachusetts; and, indeed, seems even yet to retain its influence over it. This community wholly failed to realize that a final struggle was to be between concentrated lines to rival cities, and rested in the firm conviction that it would always continue to be one between rival lines to the same city. Accordingly, while New York, Philadelphia and Baltimore were stretching out to all the great centers of the West, the business vision of Boston seemed limited to the mouth of the Erie Canal at Albany, or at the farthest to the eastern extremity of Lake Ontario. Instead, therefore, of concentrating the hopes and resources of the community on the complete development of one great through line, the public attention was dissipated and the public funds were sunk in such hazardous enterprises as the Hoosac Tunnel and the Boston, Hartford & Erie railroad. Now that the railroad system has more fully developed itself, the unfortunate consequences of this mistaken policy have become at once obvious and irreparable. That policy, however, is still clung to, though rather it would seem from a popular inability to adopt any other and more positive line of action, than from any particular faith in it. The "toll-gate system," so called, as applied to the Hoosac Tunnel line, is the last illustration of a theory of railroad development now utterly abandoned outside of the limits of Massachusetts,—the theory that a community in the struggle for through business with other communities will derive more benefit from a weak competition between a number of undeveloped and incomplete railroad lines, than from the action of a single powerful and concentrated one.

Meanwhile, it was the natural outcome of the other policy in the changed relative position of Baltimore and Philadelphia towards New York which, during the early months of 1876, was gradually driving the great lines into a fiercer and more destructive war of rates than had ever been known before. New York City, and consequently the main railroad line leading to it, began for the first time to realize that its easy supremacy no longer existed, and that in the struggle of competition it had no advantages to waste. Theretofore it had always been the practice on shipments from Western points to the seaboard to take into consideration the distances of the several cities from the point of starting. A concession had always been allowed in favor of the southern points of shipment, under which originally the rate to Boston had been five cents per hundred more than to New York, that to New York five cents more than to Philadelphia, and that to Philadelphia five cents more than to Baltimore. These differences had subsequently been modified until, for some time previous to March, 1875, on all export merchandise, rates to Boston and New York were equal, while those to Philadelphia and Baltimore, though equal to each other, were five cents less than the New York-Boston rate. As the sense of pressure from the competition of the more southern through fares increased, however, the New York interests began to realize that this arbitrary rate placed them under a too heavy disadvantage. Accordingly, a new adjustment of rates was effected on a different principle. A differential tariff was arrived at, based on distance, under which, taking Chicago as a fixed point and the rate from that city to New York as the standard, a reduction from it of ten per cent. was allowed in favor of Philadelphia, and one of 12.5 per cent. in favor of Baltimore. The position of Boston was not affected by this arrangement; the old contract being still adhered to, under which, through a rebate in case of export, foreign shipments were made from Boston on the same terms as from New York.

In its practical operation this new system, based as it was on distance in miles to the seaboard, proved highly advantageous to the southern lines. While the difference in their favor was ten and thirteen per cent. from Chicago, from other points it was much larger, until in the case of Cincinnati and Baltimore it became no less than twenty-four per cent. The effect of this soon became apparent in the largely increased receipts of produce at Philadelphia and at Baltimore, indicating an alarming diversion of the export trade from New York; for the difference in rates between the ports was not infrequently almost equal to the entire ocean freight to Europe. When those controlling the New York Central road became fully awake to this fact, and when they also realized the pressure in the way of equal competition under any circumstances which Baltimore and Philadelphia, with all their perfect facilities for handling through business, could now bring to bear upon them, it naturally occurred to them that the time had come for refusing longer to concede a differential rate in favor of those who seemed in no respect less advantageously placed than themselves. In order, however, to assume a consistent position on this subject, it became necessary for the Central road to extend the principle beyond New York, and to claim a uniform rate from the interior to all the seaboard points. This principle it was perfectly obvious that the southern or shorter routes would only concede under a sense of absolute compulsion. A full trial of strength thus became inevitable.

The struggle did not, however, break out in the first place between those who subsequently became the principal parties to it. On the contrary, all through the month of March and the early part of April last, conferences were held and strenuous efforts made to hold the through lines to an understanding among themselves. At the last of these, on the 4th of April, the New York Central represented that it was under the necessity of meeting the competition of the Grand Trunk in New England, and to this those representing the other lines assented upon the understanding that this struggle was to be a local one, and was not to extend to New York, or to divert business from that city. In the course, however, of a few days, it became apparent that the contest could not be thus restricted, and as the result of a final conference on the 18th of April, at which a number of complaints were presented, the New York Central finally gave notice of the complete abandonment of all agreements, and almost immediately a general war of rates began. Between the 3d of May and the 14th of June, the fare between Boston and Chicago over the New York Central fell from $25.85 to $14, and that over the Grand Trunk from $23.85 to 12.50; while as respects freights, the rates between Boston and Chicago on articles of the first class fell from 75 cents per hundred pounds to 20 cents, and those on agricultural products from Chicago to New York fell from 50 cents per hundred to 18 cents. These, also, were the public rates, while innumerable special contracts on terms far more favorable to shippers were made wherever business was competed for. Shippers whose patronage was really worth having were, in fact, in a position to dictate their own terms; and they did it. For six months the spectacle was witnessed of railroads hauling merchandise 1,013 miles east for $3.60 per ton, and the same distance west for $2.80 per ton,—in the one case at the rate of 3.5 mills per ton per mile, and in the other at the rate of 2.8 mills; a result which made sober and reasonable the most extravagant predictions which the advocates of cheap transportation had ever ventured to utter.

No sooner was the struggle fairly developed than the true issue was boldly avowed by the New York Central,—it being to restore the commercial supremacy of New York, imperiled by the rapid development of southern rivals. As a natural result of the mistaken railroad policy which has been described, Boston counted for nothing in the struggle,—controlling only locally competing lines, and no single consolidated through line, it was in no position to assert itself, or to defend its own interests. Yet, in fact, the interests of Boston as a commercial point were more deeply involved in the issue of the struggle than those of any other city; for the mileage charge, if persisted in, could only result in transferring the whole business of exporting produce from the northern to the more southern points. Fortunately, on this point, as between New York on the one side and Philadelphia and Baltimore on the other, the interests of New York were identical with those of Boston. The issue was a simple one. It was conceded on all sides that in the case of rival or competing lines between any two given points, as Chicago and New York, the shorter or more direct route had the right, as it was termed, to establish the rate; that is, it fixed a rate, and the longer routes were obliged to meet it, regardless of their own greater mileage, the principle of charging so much per ton per mile being, for obvious reasons, inapplicable. Where, however, lines terminated at different though competing centers, it was maintained that the principle of mileage charge should apply, —that there was no reason, for instance, why Baltimore should not enjoy, as compared with Portland or Boston, the full advantage of its geographical situation. If conceded, this principle could have practically resulted in but one thing: whenever railroads could obtain paying rates, the volume of produce seeking export would have gone irresistibly to the nearer or more southern ports; whenever, on the contrary, rates were very low, the tendency would have been towards the northern ports. This necessarily came from the fact that upon a high or 50 cents per hundred rate, with a mileage difference of ten per cent. in favor of the more southern port, the charge to that port would be as much as 5 cents a hundred less than to the more northern port, which would be sufficient, as experience had shown, to draw the business almost exclusively into that channel. If, on the other hand, rates became very low, falling to 15 cents a hundred, then the difference in favor of the southern points would be but 1.5 cents, and this might very possibly not prove a sufficient inducement to divert the course of trade from its natural outlets through the northern ports. While the managers of the Baltimore & Ohio and the Pennsylvania roads insisted, therefore, on the differential allowance, those of the New York Central met them by fixing rates at so low a point that the differential allowance, when insisted upon, could not amount to enough to influence the course of traffic. It is not yet apparent, so far as the railroads are concerned, what the effect of the process involved in carrying out this method of warfare has been. Before the substitution of steel rails for iron, the roads could not possibly have endured the test. As it was, some idea may be realized of the wonderful economy which has been attained in the movement of merchandise, from the fact that as a regular thing a ton in weight was moved 450 miles from Buffalo to New York for $1.50, whereas in the early part of the century it would have cost $100. Meanwhile, there is some reason to suppose that under certain favorable conditions the transportation of freight even at this rate is not unremunerative to the companies concerned in it. Indeed, judging by their published reports while the recent struggle was going on, it might not unfairly be inferred that throughout it the trunk lines were realizing a quite satisfactory profit on their entire business. Naturally, however, each of the leading competitors then felt obliged to insist that it was suffering least of all, and was, indeed, in a position to continue the struggle indefinitely. Accordingly, they none of them reduced their rates of dividend. In point of fact, however, there can be little doubt that the resources of all, even the strongest of the railroad companies, were heavily strained in carrying on the struggle, while many of the smaller and weaker ones were driven to actual bankruptcy.

Having practically lasted for over eight months, the struggle has been brought to a close while this Report is passing through the press (December 16). Of the arrangement arrived at, and of its bearing on the interests of the several seaboard points, it would, therefore, be somewhat premature to now venture an opinion. It was based on two distinct principles. A differential rate, computed on mileage distance, was conceded to the southern lines on all shipments from the West to the seaboard for home consumption, while equal rates were to be allowed on all foreign shipments wholly irrespective of the port through which they were made. If, for instance, a car-load of wheat was shipped at Chicago or St. Louis for Baltimore and no further, it was to be carried at a rate of thirteen per cent. in the one case, and fourteen per cent. in the other, less than if it were shipped to New York. If, however, the car-load was originally shipped to Liverpool, it was to be at the same rate for the entire distance, whether it went through New York or through Baltimore; and if, having reached Baltimore or New York at the local rate, it was then shipped to Liverpool, such rebates were to be allowed as would equalize the several ports. As respected local rates, so called, the simple difference between this arrangement and the one which preceded the conflict was, that the excessive difference in favor of Philadelphia and Baltimore on shipments from points south of Chicago was fixed at one given percentage. Under the previous arrangement this had varied from fourteen per cent. reduction from the New York rate in the case of St. Louis shipments to Baltimore to twenty-four per cent. reduction on shipments to the same place from Cincinnati. In place of this, two points and two corresponding differential rates were now fixed,—a concession of ten per cent. from the Chicago-New-York rate was made in favor of Philadelphia, and thirteen per cent. in favor of Baltimore on all Chicago shipments; and another allowance of nine per cent. in favor of Philadelphia, and fourteen per cent. in favor of Baltimore, on all St. Louis, Indianapolis and Cincinnati shipments. The new basis of agreement seems, in fact, designed to secure equality on foreign shipments to all the exporting points, while on local shipments a slight advantage is given to New York in the northern part of the great district in which all the trunk lines compete, and a larger advantage is given to Baltimore in the southern part of that district. Boston, for the reasons already stated, necessarily shares in a fixed proportion in the advantages or disadvantages which ensue under the practical working of the arrangement to New York.

The chief objection to the arrangement is an obvious one. It apparently settles nothing. In operation it cannot but be found too complicated to admit of the parties long abiding by it. The absolute want of faith and of confidence in each other which has hitherto marked the proceedings of those managing the great trunk lines, cannot but find ample field for development in the practical working of a system so intricate. The question of rebates on ocean shipments will admit of infinite wrangling. Apparently, in order to arrive at a decision in each case, it will be necessary to ascertain not only the ocean rate actually paid on that particular shipment, but also what was the rate on the same day to the same destination from the other ports. Practically, such questions, arising the whole time, must prove impossible of decision except by the dictum of some common tribunal, for which no provision is made. This combination, therefore, like the many which have preceded it, lacks, so far as can be judged, the elements essential to its permanence. There is no one either authorized or competent to keep the peace between the high contracting parties. Each reserves the right to construe the agreement to suit itself, and to refuse obedience to the decision of any one else. There is neither a court of common arbitrament, nor, even if there was, do the contracting parties show any disposition to put themselves under sufficient bonds to ensure their acquiescence in its decisions. Without this, all railroad combinations in this country, where a division of territory is impracticable, will prove but temporary. Even were they, under certain conditions, practicable, they are not so now, owing to the fact that the whole complicated system under which through or competitive railroad business is done is curiously vicious and extravagant, and must be radically reformed as a preliminary to any final settlement. It now implies the existence of a vast army of subordinates whose very existence depends on that not being done which those controlling the lines which feed them are continually trying to do. To realize the truth of this fact, it is but necessary for any person to walk down the leading business streets of any considerable town in the country. He will see that a great number of expensive offices bear the signs of railroad companies and of car and dispatch lines, and at them tickets can be purchased and rates of freight made which are binding on all the companies included. The rents, salaries and perquisites of this army of retainers all come out of the railroad corporations, and the interests of the retainers and the corporations are exactly antagonistic, —the first are always working to bring about railroad wars, in which business with them is brisk, while the last are always striving to effect combinations.

As long as this state of affairs continues, periodic railroad wars will continue. The hopes of stockholders and the fears of the business public in regard to their ceasing will be equally disappointed. A conference of those controlling the trunk lines which began its labors by clearing away the whole complicated machinery through which competitive business is fought over and secured, and then completed them by establishing a common board of arbitrament over points of dispute, clothed with a real executory power,—such a conference might result in something For this, however, no one seems as yet to be ready, and the trials of strength must, therefore, continue. Meanwhile, each year the results of the attempts at combination become weaker and verge more nearly on the ludicrous, while the wars become longer and sharper and the resulting rates permanently lower. It is not probable, however, that the recent conflict will be immediately renewed. The severe losses and bitter experience of the last few months will not be forgotten at once, and for a time matters of dispute will remain unsettled, and breaches of compact will pass unnoticed. Meanwhile, so far as the railroad system of the whole country is concerned, it is necessary to bear in mind that these continually renewed struggles between the great continental and competing trunk lines are but incidents in a phase of the process of development. The railroad interest of the country is consolidating, and it is doing it through the survivorship of the strongest. Each new war of rates is made more severe than that which preceded it, and the weaker corporations find themselves continually nearer the end of their resources, and less able to sustain the pressure. As they succumb under it, they are absorbed through bankruptcy by the yet solvent lines, as fast as these see their advantage in absorbing them. Competition is, therefore, as rapidly as possible resulting in consolidation, and this process seems likely to continue indefinitely through the immediate future. What shape this consolidation will ultimately assume, in another and later phase of development, it is futile now to consider.

Returning, therefore, to the combination of December 16, and its probable effect on the interests of Massachusetts and of Boston, the members of this Board see no reason to modify the conclusions they have heretofore expressed. There seems to be no real ground for apprehending local disadvantage from any railroad combination which has been or is likely to be effected. On this subject they, a year ago, expressed themselves as follows:—"However it may be under exceptional circumstances and for brief periods, in the long run active competition between the through routes, cannot but be prejudicial to Massachusetts' interests. It leads directly to discrimination in favor of rival communities. It does so for the obvious reason that, as a rule, railroad competition is and must continue to be stronger to New York and other seaboard points than to Boston. . . . .

"In the struggle of competition, therefore, Boston stands in a poorer position to protect itself than any other seaboard city. In the long run, the discrimination will surely be against it, in the future as in the past.

"It would seem, therefore, to be the true policy of this section to encourage, rather than to discourage, a general public combination of the through railroad routes, based on principles of equality and stability. The law of the strongest does not work in our favor, and we cannot permanently steal business. Before a permanent combination is arrived at, however, there are certain principles the concession of which, as a part of the accepted policy of any general railroad system, is essential. Foremost among these is the absolute equality of the Atlantic seaboard centers as respects the movement of merchandise to and from certain of the great distributing points of the West."

It has been seen, that in this last essential respect, the result arrived at on December 16 is in the nature of a compromise—the principle of equal rates on produce for export being acceded to on the one hand, while for local business a differential rate is conceded on the other. The final solution of the controversies between the great through lines is, however, yet to be arrived at. This compromise, however, is most unlikely to prove a final solution of the controversies between the great through lines, for the simple reason that it must, apparently in practice, work adversely to some of them. New York is not yet ready to see its commercial supremacy pass away from it; nor will Philadelphia and Baltimore quietly surrender the commercial advantages they have so hardly won. But the experience of the last few years would seem to warrant a conclusion that New York, in this matter, can no longer afford to concede anything,—that those having charge of the interests of that city must insist on absolute seaboard equality. In that case, the present truce is simply to permit the trial of an experiment, the result of which will be a renewal of hostilities over the old issue. Did Massachusetts and Boston possess an independent line, which could be wielded exclusively in their interests, they would unquestionably be strongly disposed to insist on the full enjoyment of all the great natural and geographical advantages of their city, as a recognized part of any permanent settlement. Under the circumstances, however, they are wholly dependent on such chance and suicidal competition as the Grand Trunk Railway may be disposed to wage with its more powerful and direct rivals. This in the future is unlikely to prove so active an element in the problem as in the past. The Grand Trunk, being financially the weakest of the through lines, has apparently suffered in the recent conflict much the most severely of them all, and a continuance of it would not improbably result in plunging that company more deeply than at present into bankruptcy. Its connections, also, in New England have felt the strain very severely, and have neither the means nor the disposition to endure it longer.

Finally, the present situation, and the conclusions which may apparently with some degree of confidence be deduced from it, can be briefly summed up as follows: As respects what is known as through business, the period of active railroad competition has of late entered on a new phase,—that of competition between rival termini instead of between rival lines to the same terminus. In the course of this struggle, so far as Massachusetts and Boston are concerned, an equality of advantages with other localities seems to be secured through a community of their interests with those of New York, and it must depend upon our local railroads, and especially the business community, to afford such facilities of handling and of transit as will constitute an inducement to traffic to seek this channel. The vital advantage of an independent thoroughfare, on which the whole future of Philadelphia and Baltimore seems to so great a degree to depend, is lost to Boston, and under present circumstances it is very difficult to see how it can be recovered. Indeed, the true policy for this community to adopt would not seem to dictate even an endeavor to recover it, for it is as useless to attempt at certain stages of development to abandon a long-established plan and to adopt a new one, as it is to stand still and repine over lost opportunities. Good or bad, the policy of Massachusetts as respects its through railroad connections has been adopted, and more than twenty years of time and twenty millions of the public money have been expended in the attempt to carry it out. It only remains to do so logically, with as much foresight and at as little outlay as possible. To bring anything to pass, however, a definite plan is essential; not only must there be a distinct end in view, but all efforts must be concentrated on the attainment of that end. Now, the fundamental idea of the recent Massachusetts' policy has been local railroad competition,—the same local competition, whether to the Hoosac Tunnel "toll-gate," or to Albany or to Ogdensburg. The horizon has always been a limited one, proper to the conditions which existed a quarter of a century ago. To bring anything about, it must be extended. The results accomplished in their own interests by other communities should, as far as possible, be appropriated for New England. A local competition must give place to a continental competition,—the bounds must be transferred from the Hudson to the Mississippi. This can now only be done by drawing the great thoroughfares to the other seaboard cities into New England. The Hoosac Tunnel, instead of being a "toll-gate," must become part of a trunk line, and that trunk line, instead of competing at Albany with the Boston & Albany for the traffic which flows over the New York Central, must be extended to the interior, bringing to us the whole competing force of the Erie and the Pennsylvania, and even the Baltimore and Ohio. This subject, however, has already been discussed in an official report in connection with the tunnel line made to a previous Legislature, and, as it more especially relates to the best way in which that line can be utilized, its further discussion at this time would seem to belong rather to those to whom the management of the tunnel "toll-gate" is at present intrusted, than to the members of this Board.

Chas. F. Adams, Jr.,
A. D. Briggs,
Francis M Johnson,
Railroad Commissioners.

VENTILATION OF THE HOOSAC TUNNEL.*

By THOMAS DOANE.

There is very little published information concerning tunnels.

Mr. Charles S. Storrow says, (Senate Document, No. 93, year 1863, page 21 of appendix), very little has been published in England upon the subject. Mr. Forrest, the Secretary of the Institution of Civil Engineers in London, who kindly assisted me in my enquiries, ransacked the Library of the Institution for me, and took down everything he thought would prove interesting, but the list was lamentably small, and the accounts meager. The most complete English work was entitled "Practical Tunnelling" by F. W. Simms, which gives full description of two important works.

Mr. Storrow also says, page 59 of said appendix: The *only* French Tunnel of which I could find any published description, was the Tunnel of St. Martin D'estraux.

It is probable that the report of the Commissioners upon The Troy and Greenfield Railroad, & Hoosac Tunnel, above referred to as Senate Doc. 93, year 1863, with the appendix, etc., is the best work extant upon Tunnels. To this, therefore, we are mainly confined, as to the ventilation of tunnels, while the ventilation of Mines may aid somewhat in coming to conclusions.

It may be taken as a *fact*, that the Hoosac Tunnel will require ventilation. It is probable that locomotives of the present mode of construction will be used in the tunnel more or less at least. The grades rise from both ends to the center of the tunnel, at the rate of about $26\frac{4}{10}$ to the mile. An engine passing *up* these grades must discharge large quantities of smoke, but very little while passing down. If there are many trains, and many must be expected, or the tunnel has been built in vain, they are passing in *both* directions and must discharge smoke through all the portions of the tunnel, about equally.

If smoke-consuming engines are used, like the Weston or others which may be invented, there are invisible resultants of combustion, like carbonic acid, and sulphurous gases, which must be removed from the tunnel. This is necessary in order to procure a *pleasant* as well as a *wholesome* atmosphere for those who have the care of the tunnel, and for those who shall pass through either upon freight or passenger trains.

Still another reason for ventilation is that the dust and dirt resulting from

* A paper read before the Boston Society of Civil Engineers.

smoke and from the traffic through the tunnel, so far as it may for a time float in the air, may be carried out of the tunnel. The tunnel has been open for business, and that of small amount, for about one year, and already the sides and floor have a thick covering of black dust and soot. Some of this and perhaps the most of the fine black portion comes from the lamp of the workmen engaged in lining the tunnel, in which kerosene oil is burnt, and which will not perhaps be used after the tunnel is finished.

There will, however, be large deposits of solids from smoke, unless smoke consuming engines are used, and a large portion of these can be got rid of by rapid ventilation. Unless this is done, there will be large accumulations of filth in so long a tunnel, where fires cannot, before entering the tunnel be prepared for a shoot through, as in short ones.

There is still another reason why the *maximum* of ventilation should be provided for and maintained.

The masonry with which the tunnel is lined, is not entirely, nor is it largely, made up of hard brick. The bricks used absorb of water from fifteen to thirty-two per cent. of their cubic capacity. Many portions of the rock tunnel are very wet, all of it more or less so, and therefore, if the masonry on the unprotected rock is exposed in this saturated condition to freezing, the masonry will scale, and the rock will be thrown down. Even, if through the protection of doors, *frost* does not reach inside the tunnel, the continual presence of water will carry on gradual decomposition, already begun. The air of the tunnel in a *quiet state* is full of moisture up to the dew-point, but, if ventilation as rapid as possible be kept up, the masonry and the rock will, upon their surfaces, and to some extent within, be brought into their dryest possible condition, and, therefore, into their safest and most durable state.

Again, it has been proved by experience, that a train can be hauled up a grade outside of the tunnel of forty-two feet to the mile, easier than upon the grades of $26\frac{4}{10}$ feet per mile within the tunnel. This may be accounted for in many ways, among which are the following: While workmen are engaged in lining the tunnel, oil and tallow are spilled upon the rails, preventing the driving wheels from getting hold of the rails. Again, while passing under the arches in process of construction, and among the men, the speed of trains has to be reduced, and sometimes they are brought almost or quite to a stand, thus involving irregularity of speed, and greater strain upon the engine, in passing hard spots. But there can be no question, that the large amount of moisture upon the rails preventing adhesion, and the closer condition of the air, preventing combustion, have much to do in making the easier grades *within* harder to surmount than much heavier grades *without* the tunnel.

Once more, the tunnel is sufficiently *dark*, under the best of circumstances. When filled with smoke, or with vapor, it sometimes becomes impossible for workmen to keep about their business, and the head light of a locomotive will not show the track ten feet in advance of the pilot. Workmen should be able to see the light of any approaching train some distance away, and it is of the utmost importance that the track should be visible to the engine man many hundred feet ahead of his train. The great danger to trains in the tunnel will not be from rocks falling upon the train, but from running the trains upon rock previously fallen upon the track. It is to be presumed that few rocks falling from the roof will be sufficiently large to derail the train, while a small piece lying upon or near the rails, would throw off, and wreck a train; and, besides, any given train passing the tunnel once a day, as in any given spot under a weak roof but a moment of time, while gravity is at work upon this weak roof all of the twenty-four hours, and may much more probably result in a fall and a wreck, because of the great difference of time in which the exposure is of one *part* or the other. It is, therefore, important in *this view* to maintain the largest amount of ventilation possible.

The reasons for abundant ventilation then, may be recapitulated as follows:

1st. To remove *smoke* and *gases* from common engines.

2d. To remove gases from smoke consuming engines.

3d. To carry out of the tunnel before deposits the *solids* of smoke.

4th. To preserve the atmosphere in a *pure* condition, so that it shall be *pleasant* and *wholesome* for employés and passengers.

5th. To preserve the tunnel in as *cleanly* a condition as possible.

6th. To preserve the brick masonry, of which there will be about two miles in the tunnel, in as *safe* and *dry* a condition as possible, and to prevent scaling by frost.

7th. To keep the exposed rock of the other three miles in a *dry* state, and thus save it from falling or exposure to frost.

8th. To provide and maintain a rail of greatest possible *adhesion*.

9th. To maintain a *transparent* air, for the workmen in care of the tunnel and track.

10th. To maintain a transparent air for the train men, so that accidents to trains be reduced to the minimum.

TESTIMONY OF EXPERTS AS TO THE NECESSITY OF CENTRAL SHAFT FOR VENTILATION.

From Senate Doc. 93, year 1863, page 51, we learn the opinion of the Commission, John W. Brooks, S. M. Felton and Alexander Holmes, the first two of whom are eminent as Civil Engineers, when they say they regard "the (central) shaft as likely to be the main dependence for ventilation."

They again say, upon page 52, "as the (central) shaft will most likely become the main reliance for ventilation, it should be of liberal dimensions and we would recommend it to be of an area equal to a circle of twenty feet diameter."

At page 35 they say, "the character (of the Hoosac Tunnel) is so unusual, that they have not felt at liberty to neglect any means of inquiry which promised to give them light in regard to it;" and also at same page, "the railroad tunnels in this country, which from the nature of the ground cannot be provided with ventilating shafts when necessary, at moderate expense, are so short, that the question of ventilation has not necessarily been of much influence in determining their character. In the Hoosac, this is one of the great questions for consideration." At page 47, they say, "It is not unusual for tunnels in Europe to have a summit within them, where the track is a few feet lower than the roof at the highest end, but Mr. Storrow heard of no case like the Hoosac."

CENTRAL SHAFT INDISPENSABLE FOR VENTILATION.

From Commissioners report, Senate Doc. 93, year 1863, page 49, we find that great care has been taken to obtain the opinions of the best authorities in England and on the Continent among those of the most enlarged experience, both as to the construction and use of long tunnels. . . . "These authorities are all perfectly agreed that a shaft in the center is indispensable."

Mr. Storrow obtained the views of many more persons qualified to judge, than he has named in his report.

At page 34, of appendix, to said Doc. 93, we find Mr. Brotherhead, who is not only a contractor of high character and standing, but also the owner of a very extensive machine shop and forge works, saying, "unhesitatingly that there *should be a shaft* in the center at the summit," and on page 36, that it should be for ventilation.

On page 42 of appendix, Mr. Michael Lane, Engineer, a gentleman of very great practical experience, and long association with Mr. Brunel, and, with important works upon the Tunnel under the Thames at London, says: "The central shaft would certainly be required, both to save time and furnish ventilation, for with a summit within the tunnel it was *indispensable* for the latter purpose if necessary for the other."

At page 42 of appendix again, we find that Mr. Sacré, Engineer of the Woodhead Tunnel, nearly as long as the Hoosac, Mr. Richardson, Engineer of the Bristol and South Wales Junction Railway, Mr. Mc Clean, and his partner Mr. Stileman, who enlarged the Lindal Tunnel, both distinguished engineers, Mr. Watson, a gentleman connected with Sir Morton Peto and Mr. Betts, and Mr. Thomas Brassy, "all concur in the opinion that . . . the central shaft with such a line as ours is indispensable."

At page 74 of appendix, Mr. Storrow says: "In conversing with French engineers in relation to the Hoosac tunnel, I found a most decided opinion that the central shaft would be indispensable."

At page 113 of appendix, Mr. Sommeiller, one of the engineers of the Mont Cenis Tunnel, says: "A central shaft for our line, he thought, indispensable, and . . . felt that in the possibility of such a shaft, we had an infinite advantage over their own work, where such an aid either for construction or ventilation, is altogether beyond their reach."

At page 118 of appendix, Mr. Storrow, in summing up the conclusions to which he has arrived, says: "Believing as I do that a central shaft is *indispensable*, I assume, of course, that it will be constructed."

On page 131 of said appendix, Mr. Benj. W. Latrobe, of Baltimore, who has had great experience in tunneling, says: "These shafts (for on same page he proposes two) I consider *essential* for the three-fold purposes of expediting the work, insuring its correct alignment, and for better ventilation;" and at page 137 he estimates for two (2) circular shafts of twenty feet diameter each.

On page 187 of appendix, Mr. James Laurie, of Hartford, an engineer of large experience, says: "Still, in a tunnel of the great length of the Hoosac, with a summit in the middle and the entrance nearly at the same level, there may be doubts whether, with numerous trains passing through it, a speedy and perfect ventilation would be established. Any fears on this point could be overcome by sinking a shaft near the center. The ventilation could then be regulated if necessary, by the common expedient in mining regions of keeping a fire burning near the top or bottom of the shaft."

The testimony of the above-named distinguished engineers and contractors, and the universal opinion among all consulted, pointing to the *absolute necessity* of a central shaft for *ventilation*, is dwelt upon at this length, because there are some styling themselves *practical* men, who deny the necessity of the shaft for *this* purpose, and claim that it should be *closed up*.

The testimony, unless it can be refuted by actual experience in the Hoosac Tunnel now open through, should be conclusive in determining whether to arrange the central shaft for ventilation or to close it up permanently.

It cannot be thus refuted. During the past winter, and in cold weather, an attempt has been made in a small way to test this question. The central shaft has remained closed near both its top and bottom by timber floors imperfectly laid, and leaking about their edges and through the cracks in the boards. In these floors are traps about four feet by six feet, equal to twenty-four square feet. It was proposed to close these trap doors and let them remain until it came to the knowledge of the many workmen in the tunnel, by reason of the accumulation of bad air, and then to open them and the whole shaft fully. It was further proposed to make observations as to temperature, direction of current of air, smokiness or clearness, passage of trains, direction of trains, direction of outside winds, &c., &c., at each end, at central shaft, and at two points each half way between the ends and central shaft during the time of closed shaft and open shaft. These latter data, though with only the trap door open and not the whole shaft open, and taken by observers walking through instead of by separate observers simultaneously, have been furnished me. But the shaft did not remain closed long before there was a demand on the part of the workmen to have it opened, when before they had deemed it unessential and had even claimed, contrary to the fact, that it had been closed all winter. It should be remembered that during the progress of the work, too, of enlarging and lining the tunnel, many men have been so overcome by the impure air, as to become helpless, when they were taken out of the tunnel upon cars. The question may be raised, why did they not secure better ventilation if it could be had, and in reply it may be said that the strong drafts thus raised, were uncomfortable to some of the men, inconvenient in causing lights to flare, besides making the tunnel so cold as to interfere in the making and use of mortar.

Some of the natural circumstances by which the Hoosac Tunnel is surrounded are unfavorable to natural ventilation without a shaft. The magnetic bearing of the line of the tunnel is N. 80° 25′N, and its true bearing, when corrected for variation of the needle, almost exactly East and West.

The elevations of the two ends of the tunnel are very nearly alike, and both ends are about equally exposed to sunlight and heat, the one in the morning, the other in the evening.

In *most* European tunnels, the grades are rising in one direction entirely through them, and sometimes at a rapid rate. They thus become an inclined chimney, and being short, manage to ventilate after a fashion.

In the Mont Cenis Tunnel, which more nearly corresponds in magnitude to the Hoosac, than any other completed, natural circumstances, in combination with the grades, led its projectors to expect natural ventilation without a shaft, which in their case was impossible, and so far as known, they are very little disappointed in their expectations.

At page 110 of said appendix, they say, as regards ventilation, "after the tunnel shall have been completed, they have no fears, and do not expect to require the aid of artificial means.

"The completed railways on both sides of the tunnel, and with which it is to be connected are single track railways. Yet they have insisted upon a tunnel large enough for a double track. Whether one or two tracks shall eventually be laid, they consider this section as the smallest that would answer for purposes of ventilation. They mainly depend upon a natural current of air, which they expect through it. Modane is in a cold valley on the *North* side of the mountain. Bardonneche is a much warmer valley on the *South* side."

Mr. Grattoni said, "that observations which have been continued for three years, show that there is almost universally a great difference in the temperatures between the two ends, and also in barometric heights."

Taking also into consideration the prevailing directions of the winds, and the fact that the Bardonneche end, "besides being the warmer end," is 435 ft. higher than the other, they see reason to expect an almost constant current from north to south through the tunnel.

In the *Engineer*, of January 21st, 1876, Vol. 41 page 40, Mr. G. J. Marrison, in a paper read at London, says that: "at the Mt. Cenis Tunnel, there are now sixteen trains per day, and there is not much urgency for better ventilation, but that if there were twenty trains per day, mechanical ventilation would probably be an absolute necessity."

The area of the section of the Mont Cenis Tunnel above top of ties, and consequently area of ventilation as nearly as can be estimated is $457\frac{83}{100}$ square feet. In form, its curves of shortest radius is at the crown, having in this respect the advantage in ventilation over the Hoosac, where the curve of *longest* radius is at the crown. Its center height is twenty-one feet above ties, while the Hoosac is but $18\frac{71}{100}$ feet.

That there will be smoke or deleterious gases is in the tunnel, which should be taken away, there can be but little doubt.

Mr. Storrow, at page 15 of appendix, says of the Sopperton Tunnel, which is one mile long with a grade all the way through in one direction of $75\frac{43}{100}$ ft. per mile: "As the tunnel now is, I was told that the men work in it all day whenever necessary, although they do not like to, but that if two (2) freight trains should follow each other up without the smoke being cleared away, it would be very difficult for them to work, and if four (4) trains followed each other, it would be impossible." And again page 16: "I stood a few yards outside of the tunnel when a heavy coal train passed up and came out of it with an additional engine pushing in the rear; the smoke and vapor were extremely thick, and as seen from the outside the whole entrance of the tunnel was a black mass." This tunnel is twenty-eight feet wide and twenty feet high.

Mr. Latrobe says, page 127 appendix, that in the longer tunnels such as the Kingwood on the Baltimore and Ohio R. R., (4100 ft. long), "inconvenience is at times felt at the smoke of trains;" and again, "the smoke and gas affected, at times, the workmen engaged in arching the Kingwood and Broadten tunnels on the Baltimore and Ohio R. R. so as to make it expedient, in connection with other interruptions to the work, to resume the use of the temporary tracks over the tops of the ridges."

Ventilation of some sort and to some extent being requisite, it will be best to be rid of the smoke as *early* as possible.

Without a central shaft, the entire cubical contents of the tunnel must pass one way or the other, entirely through the tunnel. If there were a central shaft *operative*, the tunnel would be ventilated in one half the time, or rather, there would be but *one half* the amount of bad air to pass through either section of the tunnel.

Judging by the limited experience already had in the Hoosac Tunnel, we conclude the weight of evidence to be on the side of the necessity of maintaining ventilation through the central shaft. Though there are about 400 men with half as many lights, at work vitiating the air, there are but few trains through the tunnel. These are confined to the use of wood in the engines, and even with every precaution and twenty-four square feet open in the shaft, the men are often compelled to descend from their work in the roof. There are also very many occasions when, with the best of lights, sight will not reach beyond a few feet.

It is, therefore, taken to be proved, both by testimony, experience and common sense, that the *central shaft* is *indispensable to ventilation.*

The next question is *how to make it most useful?*

The data given are the following:

The size prepared for the central shaft (Senate Doc. 93, year 1863, page 52 of report and page 137 of appendix) was equal to a circle of 20 feet diameter, which is 314$\frac{159}{1000}$ square feet. The shape and size decided upon was an ellipse, 27 feet by 15 feet whose area is 318$\frac{086}{1000}$ square feet.

Its location is *over* the tunnel, its major axis lying parallel to and over foot north of the center line of the tunnel. The section of the tunnel above top of ties is as follows: in solid rock, 24 feet wide and 18.71 high, containing 409$\frac{18}{100}$ square feet. In rock where lined with masonry with vertical sides, 26 feet wide and 21.21 high, containg 478$\frac{92}{100}$ square feet. In soft rock where lined with masonry and with invert, 26 feet wide, 22.71 feet high, containing 505$\frac{935}{1000}$ square feet.

The grades are as follows: beginning at the east end, there are 2118 feet of grade rising at the rate of 18.48 feet per mile, then 10500 feet rising at the rate of 26.40 per mile, then 219 feet of level to the central shaft, then 115 feet more of level, then 12129 feet, falling at the rate of 26.40 feet per mile to the west end. The elevation of tie-grade at east end is 768.87 feet above tide, of tie-grade at central shaft 828.81 feet, and of west end 768.41 feet. The height of east portal roof above tie grade, as before stated, 18.71 feet, and of west portal roof is 22.71 feet.

The difference of level between tie grade at east end and central shaft is 59$\frac{94}{100}$, and between west end and central shaft is 60$\frac{40}{100}$ feet. A level line drawn from the roof of the east portal, will strike grade at a distance of 4376 feet within the east portal; and a similar level line from the roof of west portal, will strike grade at a distance of 4542 feet within.

The following diagram will illustrate this:

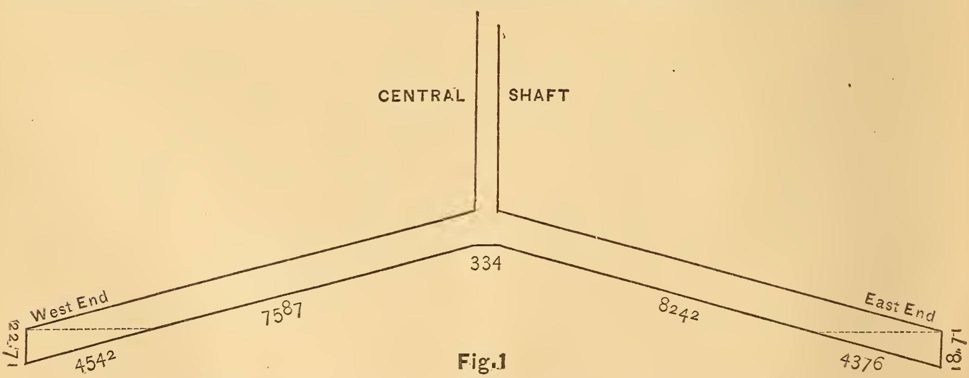


Fig. 1

Here we have $\frac{4542+4376}{2}+7587+334+8242=20622$ feet of the length of the tunnel lying in what may be called an attic, and entirely enclosed, while but $\frac{4542+4376}{2}=4459$ feet are exposed to ventilation through the portals. There is then only about $\frac{1}{6}\left(\text{exactly } \frac{4459}{25081}\right)$ of the length of the tunnel, and consequently but one-sixth of the volume of the tunnel, calling the section a parallelogram as much of it is very nearly, that can be ventilated through the portals without the aid of the central shaft, or of an exterior wind flowing either eastwardly or westwardly, through the tunnel. It is plain enough that the direction and force of the winds cannot be relied upon, and therefore that some other means must be used.

Will the forcing in of compressed air, by means of the water power and compressor at the east end, answer the purpose? It has been suggested that *this* will be necessary. A little calculation will show what can be done in this way. The compressor, No. 1, which was used for seven years at the east end, has four cylinders, 13 inches diameter, and 20 inches stroke each, and make sixty revolutions per minute. It will furnish 363 cubic feet of air per minute. The average area of the tunnel may be taken at 464 square feet, so that by this process $\frac{363}{464}$ feet$=\frac{78}{100}$ foot per minute will be ventilated, and this represents the velocity of the air current. As the tunnel is 25,081 feet long, it will take 32,155 minutes = 22 days and 4 hours of 24 hours each to ventilate it *once* through. The tunnel then can be ventilated in this way about once a month provided all trains be stopped during that time.

Should the atmosphere, however, prove so bad, under a heavy traffic, and with the best of ventilation possible, as to be unendurable to the workmen, a pipe of compressed air discharging where work is going on, may become necessary. It would not be wiser to attempt ventilation by fans *alone* at the *ends*, and therefore the only resort is to a shaft opening at the center into the top of the attic, and this, fortunately has been provided by those who have gone before.

At page 34 of said appendix, Mr. Brotherhead says, unhesitatingly, "that there should be a shaft in the center of the Hoosac Tunnel," at the summit, and from its position and height he anticipates a great upward draft in it, *independently* of *artificial means*.

At page 45 of appendix, Mr. Storrow, in summing up his observations on tunnels in England, says: "in no one have *artificial means* of ventilation been required after their construction."

Since Mr. Storrow's visit, which was in 1862, a few tunnels in England have their ventilation *artificially* aided.

What is the testimony concerning the size necessary for a shaft? At page 23 of said appendix, we find that at the Kilsby Tunnel in England, "In May, 1836, one of the large ventilating shafts was commenced and completed in about twelve months. This shaft is sixty feet in diameter and 132 feet deep. The second ventilating shaft is not so deep by thirty feet. The great ventilating shafts, . . . are found fully to answer the purpose for which they were intended, leaving the tunnel entirely free from any offensive vapor immediately after the transit of each train." This tunnel is 7269 feet, or $1\frac{38}{100}$ miles long. The area of *each* shaft is 2827 square feet, or about nine times as great as that of the central shaft of Hoosac Tunnel.

In view of the fact that an ample operative central shaft would in itself reduce the smokiness, either as to density or duration, of the tunnel, as before stated, one-half, because the smoke from either end passes up the shaft instead of going through, or the fresh air coming down flows both ways instead of one, it becomes important to have it large. We cannot have it larger than it now is, but shall even this be reduced is the question.

It would seem that a shaft having not less than double the area of the tunnel would be the best, for then the current of air from the tunnel both ways *up* the shaft, or down the shaft and both ways in the tunnel would maintain equal velocities in both shaft and tunnel. But instead of 928 square feet as the sum of both east and west tunnel areas, we have 318 square feet in the shaft=about one-third.

Any reduction of area of the shaft involves an increased velocity to carry a given amount of air, or a reduction of the volume if the velocity is not increased. The latter will doubtless prove the truth.

It has been suggested that a contraction of the throat of the shaft would aid ventilation, but aside from the above objection it must be remembered that during the winter the shaft will be an upcast and during the summer a downcast, and therefore that both ends of the shaft must be reduced to form throats for the opposite currents. It has never been proved that a reduction for a throat has any value, except to pass the air through fires for the purposes of blowing them or of preventing the escape of smoke from house chimneys into their rooms. If the shaft be reduced at both its ends, it will be a practical reduction of its area to that of its smallest section and the shaft to that extent will have been built in vain. In proof of this is the statement in "Rankine's Steam Engineering," page 287 : "It appears that in using this formula, a conical or pyramidal chimney may, without sensible error, be trusted as if it were cylindrical, or prismatic, with an uniform sectional area equal to that of the opening at the top," which is no doubt its smallest area.

Again, D'Aubuissoin says, at page 220, article 203 : "Notwithstanding the great irregularities presented by these experiments, they are very remarkable, principally because they exhibit, in a very prominent manner the effect of *enlargement* existing in a conduit, an effect quite as prejudicial as that of *contraction* taken above a certain limit."

Again, "Rankine's Steam Engineering," page 572, the area of the narrowest part of the contracted vein is in every case to be considered as the vertical or effective outlet.

This evidence leads to the belief that in a flue especially when intended to be effective in opposite directions, there should be uniformity and smoothness of bore throughout, and that if this is not attained *the effective* area or dimensions of the shaft is its *smallest* area.

This shows also the importance of not only securing a clear area of flue equal to the theoretical, but that as few excavations as possible be made beyond the theoretical or construction lines, as such enlargements are prejudicial to the flow.

It is a law of flowage, that the resistance from friction *increases* as the square of the velocity of the current. With the *present* ratio between the area of shaft and tunnel, which is about as 1 to 3, the resistance in the shaft will be nine times as much as in the tunnel, and it is certainly unwise to increase the friction, and retard the flow by a further reduction of the area of the shaft.

D'Aubuissoin, at page 217, says: "To give an exact idea of the resistance which contractions of the section of a conduit for a very short extent oppose to motion, suppose that in a pipe we place perpendicularly to its axis a diaphragm, or thin plate, pierced with an orifice.

"When the fluid (or gas) in motion arrives at this, the vein will be contracted, and will also be reduced to the size of the opening. It is through such an opening, thus reduced that it is necessary to force its passage, by taking a velocity as much greater as the opening is smaller, and this velocity will always be superior to that which would take place in this part of the pipe, without the diaphragm.

The excess of force necessary to produce the excess of velocity, the direction of the motion remaining the same, will evidently be the effect of the sudden contraction; it will be the resistance opposed.

It is generally conceded that the central shaft, in order to secure the safety of trains and persons passing beneath it, must be closed with masonry and covered with some material which shall consume the force of stones falling into it. In what manner, then, shall the shaft be connected with the tunnel for the purpose of ventilation?

An opening or openings in the *center of the roof* connecting as directly as possible with the shaft would seem to be the best way. But this method is open in a slight degree to the same objection which lies against an open central shaft, that stones may fall from it.

It may, therefore, be best to place these openings at one side of the tunnel and excavate the flues down to the floor of the tunnel.

It also seems plain that two (2) connecting flues should be made instead of one, for the single flue must incline from the shaft either towards the one end of the tunnel or the other, in order to pass the arching and give an advantage in ventilation to one or the other, when they should be treated alike.

If there are two flues, the area of each should be not less than one-half that of the shaft, which one-half is equal to $159\frac{04}{100}$ square feet.

On page 204 of D'Aubuissoin, we find that the resistance to flow, or friction, is in the *inverse* ratio of *diameters.* For this reason, and because the connecting flues must be indirect, some increase of area must be made to get the benefit of the full section of the shaft. It is advised to give each flue an area of 180 square feet.

The next question arising is, what shall be the linear direction or alignment of the flues? It has been proposed to begin them at equal elevations, say fifty feet above the roof of the tunnel, upon the opposite sides of the shaft, drive them horizontally east and west about thirty feet each, and then sink them vertically to the tunnel thus:

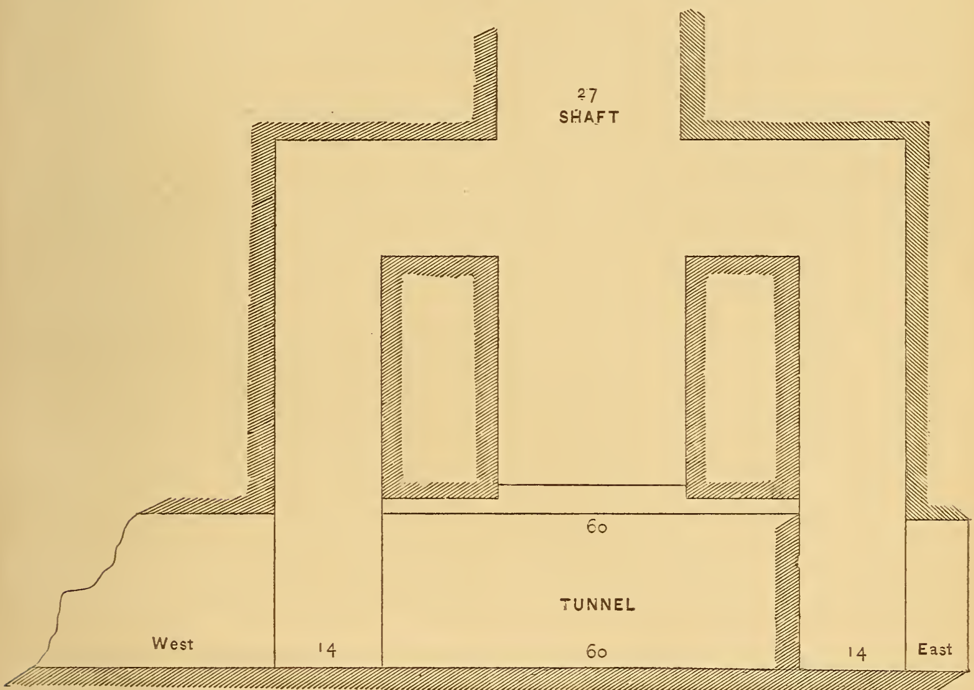


Fig. 2

Scale, $\frac{1}{200}$.

In a practical treatise on ventilation by Morrill Wyman, he states at page 122, that "in all cases of flues entering a chimney, they should be so arranged that the smoke shall assume a direction approaching that of the axis of the chimney into which they enter;" and at page 149, that "two current sentering at right angles of equal velocity destroy each other . . . this should be prevented by giving all flues a *vertical* direction as they enter the chimney."

Again D'Aubuissoin, at page 216, says: "If the effect of well-rounded curves is insensible, it would not be so with angles properly so-called. An experiment of Venoturi shows their influences." And again: "The bad effect of angles is still more manifest in the experiments of Rennie (196); with his pipe fifteen feet long and one-half inch diameter, under a head of four feet, he had per minute a discharge from the straight pipe, 0.4196 cubic feet.

From the pipe with 15 semi-circular bends (=7½ circles) 0.3694 cub. ft.

From the pipe with 1 right angle
(=¼ circle) 0.3334 cub. ft.
From the pipe with 24 right angles
(=6 circles) 0.1519 cub. ft.

So that a single angle of 90° reduced the discharge more than fifteen curves (one-half circle). This single fact shows with what care all angles should be avoided in the establishment of conduits."

The plan proposed, as will be seen by reference to the foregoing diagram, involves three vertical right angles, besides two horizontal ones, and the discharge of the two opposite flowing currents of presumably equal velocities, directly in the face of each other, and therefore for either reason, and most certainly for both, must be abandoned. The two horizontal right angles, and the lower vertical right angle, will necessarily be retained in the plan to be proposed, but the legs of the horizontal one are so short that the necessary rounding of the rock in excavating will destroy much of their harmful influence.

In order then to preserve in the tunnel the individuality of the currents of the two flues, their openings should be separated from each other by quite a space: in order to avoid the turning of more angles than absolutely necessary, there should be the introduction of a curved alignment, and in order to prevent the collision or fighting in the shaft of the two currents, a partition or brattice should be built up so far that the currents will at its top have attained to a direction in line with the axis of the shaft, and that this direction may be more readily attained, the flues should enter the shaft at as small an angle as possible.

The method proposed in the following diagram, seems more nearly than any other, to meet all their requirements:

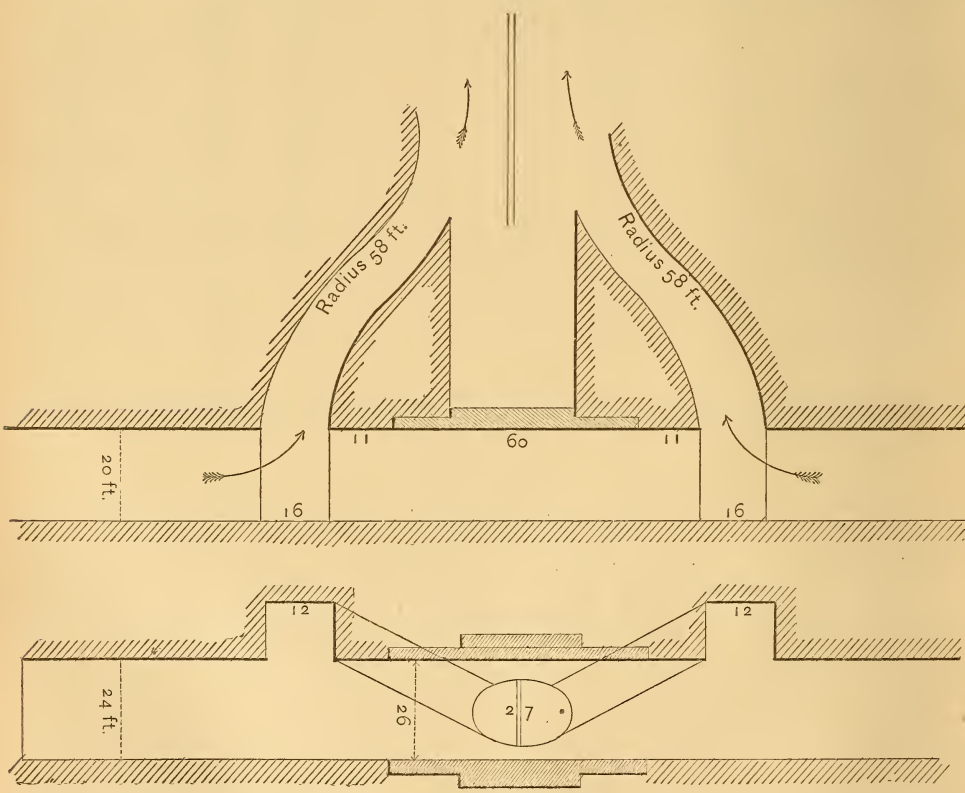


Fig. 3

PLAN AND ELEVATION OF TUNNEL SHAFT.

Scale, $\frac{1}{300}$.

An attempt has been made to get some data in the tunnel, which might help in solving the problem. The failure to make the observations simultaneous at the several stations has destroyed their value in some measure, for while a single observer walked through the tunnel ten times, in an average time of two hours and twenty minutes, there was opportunity for the smoke to follow or precede him, and for marked changes to occur, which could only be properly noted by a stationary observer.

However, some things were found which may be interesting in this connection. The observations were made between February 26th, and March 29th 1876, it *being Winter.*

It is found, with perhaps two slight exceptions which may have been errors, that there was a very uniform increase in temperature from each end towards, and to the central shaft. This was true both while the shaft was closed entirely, and when the small trap door was open, and whichever way the draft was. This indicates the truth of the position taken on page 364, that the grades descending both ways from an attic in the tunnel which will not ventilate naturally without a shaft. The hotter air also accumulates in the roof of the attic at the ridge, and indicates the proper place for shaft openings.

The notes taken on 26th February, on which day only the shaft was entirely closed, show that there was hardly a perceptible draft either way and that *both ends* of the tunnel were clear, while all the rest of the tunnel was either *smoky* or *very* smoky. This also shows, as stated on page 365, that *under such circumstances* only so much of the tunnel as lies horizontally below the roof of the portals will ventilate naturally without a shaft.

The observations alluded to show in a majority of cases, when the draft is through the tunnel either way, that the difference of temperature between the ingoing end and the central shaft is greater than the difference of temperature between the outgoing and the central shaft.

Taking all the cases, including the exceptions, and we have an average of temperature difference between the ingoing ends and the central shaft of above 19°, and between the outgoing ends and the central shaft of about 14° or a rise of 5° between the entrance of the air and its departure, both being by the portals.

The average temperature at the ends was $\frac{5}{10}$ degrees, ranging between 15° and 50°, and at the central shaft $53\frac{3}{10}$°, ranging between 51° and 62°.

It will be noticed that the temperature at the ends average 4½° above freezing, so that there would have been no danger from frost with the fullest ventilation, except in a few cases.

With the above difference of temperature of 19° between the ingoing end and the central shaft, what rate of ventilation should we expect with tunnel and shaft fully open, when a mine has two shafts of equal area, with tops and bottoms at same elevation? As soon as they are connected at the base, one will certainly become an upcast and the other a downcast; but the determining causes are so delicate, perhaps accidental, that no one can foretell which will become the upcast.

But in the case assumed, there can probably be no question but that the central shaft will become an upcast, while the exterior surface of the mountain becomes a downcast. It would be an interesting question, as to how much this downcast would be modified or affected by the mountain summits interfering between the surface openings and the shaft, and the two ends.

But the *speed* of ventilation is a more uncertain and delicate question than that of *direction.*

The central shaft, as it is stated on page 365, has an area of $318\frac{086}{1000}$ square feet. Its depth from ground to grade is $1018\frac{48}{100}$ feet, to which, perhaps, we are entitled to add the elevation of grade at shaft above that at portals, which is about sixty feet more.

The volume of air at 32° is doubled by an addition of 491° of heat. The area of a column of air being constant, its height will increase in the same ratio. How much will a column of air $1018\frac{48}{100}$

feet high be increased in height by the addition of 19° Fah., its original temperature before entering the tunnel being say $36\frac{5}{10}^{\circ}$.

$491^{\circ}+4.5 : 491^{\circ}+23.5^{\circ} : : 1018\frac{48}{100} : 1057.53$ Ans.

Logm.	495.5	7.3049563	by Rankine's rules and tables.
"	514.5	2.7113854	page 249. $V=29h$. tables.
"	1018.48	3.0079525	$V=8.024\sqrt{h}$.
Th. =	1057.53	3.0242942	$8.024\sqrt{39.05}$=velocity
	1018.48		per second in feet=
Logm.	$39.05=h^2$	1.5916210	50^{142} ft. per second=
		0.7958105	3008^{52} " minute.
Logm.	8024	0.9043909	in the shaft.
	50.142	1.7002014	

Area of tunnel, 464 square feet: of shaft, 318,086 : : velocity, 3008.52 : 2062.43 ft. velocity in tunnel per minute.

Log.	464.	7.3334820	Log.	25081	4.3993448
"	318.086	2.5025446	"	2062.43	3.3143795
				min.	
"	3008.52	3.4783529	"	12.161	1.0849653
	2062.43	3.3143795			

This speed of ventilation, which at the hurricane rate of 153 miles per hour, would clear the whole tunnel in $12\frac{1}{6}$ minutes, or about 118 times per day of twenty-four hours.

Just what influence, or rather the amount of it, the hot gases from locomotives will have, it is difficult to say, but the probability is, that it will have the effect to prolong the winter and shorten the summer conditions. From Rankine's Rules and Tables, page 115:

Log.	29.922 inches of mercury......	1.4759906
"	14.7 lbs. atmosphere per sq. in.	1.1673173
	2.0355	0.3086733
"	120 common pressure in engine	2.0791812
"	244.26 inches of mercury.....	2.3878545

From useful information (Ramopo) page 287, we find that $\sqrt[6]{244.26}\times 177 - 100$=temperature of steam at 120 lbs.

Log. 244.26................	^{6}/2.3878545
	0.3979754
Log. 177	2.2479733
442.53	2.6459487

$\frac{100}{342.53}$ temperature of steam at 120 lbs. pressure.

From Ramopo, page 174, firegrate surface in engine, say 15 sq. ft.

From Rankine's "Steam Eng.," page 285, lbs. coal per hour per sq. ft. of grate, 40 sq. ft.

From "Rankine's Steam Engineering," page 286, cw. ft. of air per pound of fuel at 572°, 471 square feet.

Then cubic feet of air discharged from smoke-stack per hour 282,600, at a temperature between 342° and 600°, without allowance for its expansion, which would about double it.

Suppose passage occupy 20 minutes, then a locomotive in one passage discharges, without allowance for expansion, $\frac{282600}{3} = 94200$ cwt. feet., which would fill a length of tunnel of $211\frac{64}{100}$ feet, as the passage of about 118 locomotives would fill the entire tunnel once full of hot air or gases, at a temperature of say 572°.

This shows a very considerable influence on the part of locomotives in producing a difference in temperature, and consequently an increase in draft.

There can be no question, whether considered in the light of theory, or from observation in the tunnel itself, that, when the air in the tunnel is warmer, and consequently lighter, then the exterior air, which is the usual winter condition, that the air from the tunnel will rise through the central shaft, and flow into the tunnel from one or both ends—depending on the direction and force of the wind exterior to the tunnel; and also that when the air of the tunnel and shaft is colder than the exterior air, which is the normal summer state, the air from the shaft will descend into the tunnel, and with that in the tunnel, run out at one or both ends, as water out of a pipe. Perhaps the change between *day* and *night* may make diurnal summers and winters, during the warmer months.

It should be said of the calculations, on this page, where it is shown that with a difference in outer and inner temperature of 19°, the entire tunnel will be ventilated in about twelve minutes; that with this speed in the current of air, it *will not be possible* to maintain this difference of temperature, and as a consequence, this speed of ventilation.

Experiments with an open shaft *have not been made*, and therefore we do not know what influence the tunnel will have in heating or cooling the air-current at different velocities, nor what influence locomotives will have in addition.

It is plain that the swifter the current, the less the heating or cooling power of the tunnel and locomotives, because the current is exposed to their influences for a shorter time. They are mutually dependent, and the range of temperature will be between say zero outside and 50° within in winter, and 100° outside and 50° within in summer, and an equilibrium of temperature and velocities will be established somewhere between.

Could a difference of temperature of 50° be maintained, the volocity resulting would ventilate the whole tunnel in about seven minutes. This condition is not possible in the nature of things, but it illustrates the influence of differences of temperature in creating currents. Let us suppose that a difference of temperature of 5° between external and internal air can be maintained usually, and confined to that limit by the use of portal gates, then we have the following results :

Assuming the internal air at 50°, and the external at 45°, then 491+13 : 491 +18 : : $1018^{\underline{48}}$: : $1028^{\underline{58}}$, and equal 1028.58 −1018.48=10.10 feet.

Log. 504	7.2975695	$8.024\sqrt{10.10}=25.507$
" 509	2.7067178	
" 1018.48	3.0079525	Velocity=$25^{\underline{507}}$ ft. per second.
1028.58	3.0122368	Velocity=$1530^{\underline{42}}$ ft. per minute.
Log. 10.10	²)1.0043214	in the shaft.
	0.5021607	
Log. 8.024	0.9043909	
25.507	1.4065516	

Area of tunnel, 464 sq. ft.; area of shaft, 318.086 : : 1530.42; velocity in shaft, 1049.55 ft. per min. velocity in tunnel.

Log. 464 cos.	7.3334820	Log. 25081	4.3993438
" 318.086	2.5025446	" 1049.15	3.0208373
" 1530.42	3.1848107	2.3906 min.	1.3785075
1049·15	3.0208373		

This speed of current will clear the tunnel entirely once in about 24 minutes, or 60 times in the 24 hours.

If the shaft should be closed by masonry, a man-hole of three feet diameter be left open, and the flues neglected, as has been proposed, we should have the following state of things, with the supposed difference of temperature of 5°.

Velocity in the shaft being as before $1530\frac{42}{100}$ feet per minute, then area tunnel 464; area man-hole 7.0686 : : velocity shaft 1530.42; velocity tunnel 23.314.

Log. 464 cos.	7.3334820	Log. 25081	4.3993448
" 7.0686	0.8493334	" 23.314	1.3676261
" 15.3042	3.1848107	⁶⁰)1075.77 min.	3.0317187
23.314	1.3676261	17 hrs., $55\frac{77}{100}$ mins.	

That is, the tunnel would be ventilated once through in about every 18 hours.

The ventilation of the tunnel will not be beneficially, but rather prejudicially, effected by the *movement* of trains. They will not push a column of air before them through the entire tunnel, nor up the shaft. The Hoosac Tunnel is too long and its open area too large to permit this. The cross-section of a moving train will not exceed 110 square feet, while the tunnel section averages 464 or more than four times as much. The air temporarily pushed before a train, will return overhead and along sides in an eddy, to supply the vacuum left behind.

In an article in the *Engineer*, vol. 39, page 30, January 8th, 1875, we find such an experience in the Metropolitan Railway of London. The tunnel is 4,200 feet, or about three-fourth mile long. The air returning from before the trains, comes again in an eddy to the rear of the train. To prevent this, the engineer puts up screens and doors overhead and at the sides, but such a course is inapplicable to so extensive a work as the Hoosac.

In the calculations of velocity of currents of air herein made, allowance has been made for the vein of contraction and for friction only in the case of the flues, which are made each 180 square feet, while one-half of the shaft area is 159 square feet. If the contracted area be taken at ninety-three per cent. of the full area of opening, we have 93×180 :

167.10 square feet, an excess still of about eight feet, and probably sufficient for friction at slow velocities.

There will be times between summer and winter, and between day and night, when temperatures in and out of the tunnel, will approximate to each other. Then there will be little *natural* ventilation. It will then, however, be true that the hotter air of the tunnel and from engines, will accumulate in the apex of the attic. It may then become possible, and in all probability *necessary* to divide the entire shaft by a transverse partition, so as to obtain a ventilation by means of two separate flues, the inside air of the roof ascending in the one, and the outer air descending by the other. In Ure's Dictionary, vol. 2, page 224, it is stated that with two such flues "it is generally found that a current of air does take place (it may almost be said *always* takes place) without any other means being employed."

The necessity for doing this, if in the hands of proper observers, will be experimentally proved or disproved, and until it be *proved*, the partition need not be put in. Nothing should *now* be done however, which will *prevent* the easy accomplishment of this end, and there is nothing in the design prepared on page 25, which will forbid the proper carrying out of the double flue plan.

There is a *chance* that with a heavy traffic *artificial* aids to ventilation will be required in addition.

In the abstract from a paper read by Mr. Marrison, to the Institute of Civil Engineers in London, to be found in the *Engineer* of January 21st, 1876, and referred to on page 363 hereof, it is stated that should the trains be increased from the present number of sixteen in the Mont Cenis Tunnel up to twenty, that *mechanical* ventilation would probably be an *absolute necessity.*

The article further shows, that with a shaft at the center there would be a great gain in convenience and power.

Mr. Marrison concludes:

1st. That long tunnels *without shaft* must be ventilated by fans at one end.

2d. That with a given amount of traffic, the power required to ventilate, varies as the fourth power of the length.

If this second position be true, it will be 509 times as difficult to ventilate the Hoosac 4.75 miles long without a shaft, as a tunnel one mile long.

But if we treat the shaft as an open end, than which if kept open, it will probably be better, we have only one-half the length, or 2.375 miles, and under the second position, the Hoosac would then be about thirty-two times more difficult to ventilate than a tunnel one mile long.

Log.	2.375	0.3756636
		4
"	31.81	1.5026544

The comparison between the tunnel 4.75 miles long and that of one-half the length, in which the one requires 509 times, and the other only thirty-two times the power to ventilate over a tunnel one mile long, illustrates, *very forcibly*, the importance of the fullest liberty to use the central shaft.

There are three prominent methods of *artificial aids* to ventilation:

By fires in a shaft or chimney;

By forcing fans, or pumps;

By exhausting fans or pumps.

When coal is cheap, a fire at the bottom of *one* flue of a double shaft would be perhaps the best method. This plan would, however, not be available if the shaft is to be maintained as a single flue, for at times the draft should be down the shaft.

The plan of forcing fans is not thought well of in practice. It has been said of air, that it is like a string which can easier be pulled through a tube, than pushed through. In Ure's Dictionary. vol. 2, page 416, it is said that "a very slight circulation of air can be effected by propulsion in comparison of what may be done by exhaustion."

This being the case, the best form of mechanical aid to ventilation, should it ever be wanted, will be by exhausting fans set at the top of the central shaft.

Fans to be efficient for such a purpose should be very large. In the old country, they are built thirty and forty feet in diameter. The *whole area* of the shaft must be reserved for their use if ever introduced.

Mr. Henry S. Drinker, who is preparing a work on American Tunnelling, suggests the application of *wind power* to driving fans.

Benjamin Gibbons, Ure's Dictionary, page 1017, in regard to mining ventilation, writes: "We should avail ourselves, as far as possible, of the *natural powers* that are at our command. But cases may arise when other auxiliaries may be temporarily required, although in the author's opinion these cases may be reduced to a very few."

THE RAILWAYS OF THE WORLD.

From "The Engineer."

THE title of this article deserves a word of explanation. The subject denoted by it is enormous. How is it possible to say anything concerning it which is worth saying within the limits at our disposal? We venture to hope that before we have done we shall be able to justify our selection. At the end of the year 1873, the Honorable Mr. Gillies, Australian Commissioner of Railways, informed Mr. T. Higinbotham, M.I.C.E., Engineer-in-Chief of Victorian Railways, that his Government considered it desirable that he should visit Europe and America, inspect the railways of those countries, and prepare a report concerning them for the information of the Australian Government. Accordingly Mr. Higinbotham left Melbourne on the 10th of March, 1874, and visited America, Great Britain, Europe, and returning by way of India, inspected most of the great lines in that country. He arrived in Melbourne again on the 11th of January, 1876, having thus been absent a year and ten months. During his tour Mr. Higinbotham met everywhere with the utmost courtesy. He was freely supplied with information, and he learned a great deal. This information he has embodied in a very terse and ably-written report of seventy-two large pages, and it is with this report on the railways of the world that we now propose to deal. It will be understood at the outset that there are multitudes of questions connected with the working of railways with which Mr. Higinbotham did not concern himself. The paramount object he had in view was to collect data which would be useful in Australia. But he has done more than this, for he has contrived to put into his report a summary description of the railways of the world which contains a very considerable mass of general information, rendering the paper one of the most valuable contributions to the literature of railways ever penned. We do not propose here to go fully into Mr. Higinbotham's report; for the present we shall content ourselves with dealing with some of the facts he places before his readers. Mr. Higinbotham went first to the United States. He reached San Francisco on the 15th of April, 1874, and his first stopping place was Sacramento city, where he inspected the workshops of the Central Pacific line. Of this road at the time there were 1600 miles open; the main line from San Francisco to Ogden, where the Union Pacific line begins, being 882 miles long. Mr. Higinbotham deals tenderly with the shortcomings of this railway, while he describes its general characteristics very succinctly. We have not space to reproduce in full his description of the rolling stock; it must suffice to say that the engines are all fitted with bogies, or "track feelers," as they are expressively termed, which carry from thirty to forty per cent. of the whole weight of the engine. The passenger engines weigh with steam up about thirty-three tons; they have seventeen inch cylinders, twenty-four inch stroke, and four coupled drivers four feet eight inches to five feet in diameter; the tenders weigh full twenty-five tons. The heaviest gradient worked is one in fifty over the Sierra Nevada. Three engines are required to take up a train of nine or ten passenger cars. These cars each weigh about thirteen tons, of which the two bogies represent about 5.5 tons. They seat fifty-two, and when the car is full the dead weight per passenger is 754 lbs. Mr. Higinbotham gives similar particulars of all the lines with which he deals. Sometimes the details are better filled in, sometimes the information is more meagre; but, on the whole, he supplies just what is wanted. We shall not attempt to follow him step by step. It will be of more interest to our readers to learn something concerning the opinions of a competent engineer, who has had innumerable opportunities of acquiring information. Mr. Higinbotham has a good deal to say, for example, concerning a much-vexed question—namely, the relative merits of English and American locomotives, and we shall confine our attention to this branch of the subject for the moment.

It has often been stated in this country, as well as in the United States, that the American locomotive is cheaper to build, to maintain, and to work than the English engine, and the statement has been disputed as often as it has been made. Mr. Higinbotham reports that all the evidence he has obtained goes to show that on bad roads, such as exist in the United States, English locomotives could not be used at all; from which it appears that the American engine has a distinct vocation, and that it is vain to draw comparisons between the two types of machine. In writing about the Pacific Railroad, for example, Mr. Higinbotham says:—"I had opportunities of speaking to several drivers, Englishmen, who had driven in England; they all preferred the American to the English engine, which, they said, could not keep on such roads as are commonly to be found in the Western States." This may be taken as unprejudiced testimony: "The road was rough, and the speed at times down falling gradients very great, but the drivers appeared to have perfect confidence that their engines would not leave the road. The bogie they consider the great source of safety." It may be said that as these men had not tried English engines on the road they could not speak from experience. In his account of the Grand Trunk Railway of Canada, however, Mr. Higinbotham subsequently says:—"The whole of the engines and rolling stock first put on the line were built in England, but the engines were constantly getting off the road, and engines and cars of every class are now of the same kind as those in the States." Further on we read:—"The bogie truck and cast iron wheels are two of the most important features of American engines and rolling stock, and both of these appear to me to have been adopted in consequence of the very imperfect permanent way and the great severity of the climate in the winter, when the road bed, which is frequently formed of earth only, is exposed alternately to intense frost and sudden thaws, which completely distort the track. Only bogie engines and rolling stock could live on such roads, as was proved in the case of the Grand Trunk Railway of Canada, where, neglecting the experience that had been gained in the States, and relying also no doubt on a better and more carefully laid road than was to be found there, English engines and rolling stock were tried, but had to be abandoned, and the American type adopted. Very recently the same mistake was made on the narrow gauge railroads in Canada, and with the same result." We cannot ignore testimony of this kind, and it may be taken as conclusively settled that bogie engines, and American bogie engines in particular, are less likely to be thrown off a road than English engines. This result is due no doubt to two causes. The first is the comparative flexibility of the American engine, the whole wheel base of which can twist itself about so as to follow the vertical or horizontal contortions of a road with great ease; while the second is that the leading wheels of the American engine bogie are left very much to themselves, and are but little exposed to the influence of the lateral motion of the engine. It was once proposed to construct an engine with six carrying wheels, the leading wheels to be set almost precisely like the fore carriage of an omnibus, while two smaller wheels, which supported none of the weight of the engine, were to run five feet or six feet in front, the end of the axle being carried in radius rods, if we may so call them, coupled to the ends of the true leading axle of the engine. The apparently idle wheels would, it was contended, never leave the road, for they would be spared all side shocks, and they would continually guide the true leading wheels, steady them, and so prevent them from leaving the rails, taking them nicely into and out of curves, and radiating them to the best advantage. There is reason to believe that the leading wheels of the American bogie in a great measure answer this purpose, and so help to keep the engine on the road. Now, it is true that English engines on English roads very seldom run off, in spite of their long and comparatively rigid wheel base; but this results not from the merits of the engine, but from the excellent qualities of the road; and it is worth considering whether an American engine, which is capable of running well on a road which sets an English locomotive at defiance, might not be found to run more lightly, cheaply, and with less practical resisttance, and less wear and tear of the track, than an English engine. In this country bogies are used almost entirely in order to distribute weight, and with little or no regard for facilitating the motion of an engine or preventing the chance of derailment; and a considerable number of bogie engines have been so badly designed that the bogie itself has suffered in reputation. But there are a great many very well designed bogie engines running in Great Britain, and it would be very interesting to know what the running expenses of such bogie engines as those on the North British Railway, for example, are as compared with the working cost of Midland or London and North-Western engines of about the same weight, and with six wheels only.

It might thus be ascertained whether a still further assimilation to American practice is or is not desirable. We have no intention of lauding American locomotives and disparaging our own; but, on the other hand, English engineers would not act wisely if they suffered a silly question of prejudice to stand in the way and shut out facts of the kind supplied by Mr. Higinbotham. Whatever this gentleman may think of American engines, it is certain that he holds the American railway car in very low estimation. He points out that the bogie system is only applicable to carriages of large dimensions, at least as bogies are made in the United States, where they weigh from five and a-half to nine tons. As regards comfort, he holds that the American car cannot compare with the English carriage, more especially for long journeys; and it does not appear that anything whatever would be gained, while a great deal would be lost, by the adoption of such cars in this country. It must be understood that the ordinary American car, to which alone Mr. Higinbotham is referring, has little or nothing in common with the Pullman palace and sleeping cars, which are admirably adapted to long journeys. We have referred so frequently to cast iron wheels in the course of this article that we ought perhaps to say something more concerning them here, but we prefer to reserve our consideration of the information Mr. Higinbotham supplies for another occasion.

Before taking leave of the American railroads, Mr. Higinbotham sums up most of the information which he has obtained. Indeed, his general rule in writing appears to have been first to explain how he acquired his information; and secondly, to lay that information before his readers. In doing this, we find that he constantly combats Victorian prejudices, or compares Victorian practice with that of other countries. Thus it appears that when strict economy was urged some years since on the Victorian Government in the construction of their railroads, it was repeatedly asserted that in the United States there were no platforms at the railway stations, whereas platforms are to be found at every station of any importance in the States. In the West they are seldom raised much above the ground, but a far larger area is allowed than is common in England. The fact that no railway signals as we understand them are used on American railroads will be new to many English engineers. The great majority of the lines being single, are worked by telegraph, and at stations by hand signals. An officer who is known as a "train dispatcher" has entire control of the running of the trains on a section of from 100 to 200 miles of road. He regulates their working by means of a diagram on which is shown the position of every train at any given moment on the section which he controls, the information of course being collected into his head office by telegraph. If a breakdown occurs, he is able to control and readjust the traffic by means of his diagram. The staff system, it seems, is never used either in the States or Canada on single lines. There is a great deal to be urged in favor of a system of this kind, which places before the controlling mind a complete picture in little of the position of the various trains in a given district almost from minute to minute; but attempts to work on a similar system in this country have not succeeded very well, apparently because it is almost impossible to induce the station-masters and other officials to communicate freely with the train dispatcher, who, it is obvious, becomes powerless the moment he is deprived of information concerning the whereabouts of a train.

For the moment we take our leave of Mr. Higinbotham's report, giving in conclusion the following expression of his opinion, which we commend specially to the attention of those gentlemen connected with the iron and steel trade who expect to find in the United States, ere long, a good market for their productions. "It is admitted in the United States that, for the present, railway construction has reached its limits, and that the progress in the future must, necessarily, be very slow and gradual as compared with the past. Among the Rocky Mountains and in similar districts, there will possibly be extensions of mineral lines on a gauge of three feet or three feet six inches; but the construction of railways for general traffic is at an end for the present, and possibly for some time to come." An expression of opinion from a man who possessed Mr. Higinbotham's unrivalled opportunities of acquiring accurate information possesses unusual value.

THE CHAIN TAG, "IROQUOIS," ON THE RIVER ST. LAWRENCE.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE Canadian Government for the last five years have been deeply engaged with the improvements of the St. Lawrence navigation. The Welland Canal has been thoroughly surveyed, and the works are now well under way. In the case of the St. Lawrence canals proper, they have all been carefully surveyed. The Lachine and Cornwall are now let and the works advancing. But with regard to that part of the St. Lawrence navigation, known as the Williamsburg Canals, nothing has been done, except the surveys, which have been very thorough. Those canals are only used by ascending vessels, descending ones go outside. The river here will not accommodate anything drawing over 9′ at low water, but it is intended by the D.P.W. to blast out a channel through the rock in the Galoups Rapids (Rapide Aux Galoups), and thus accommodate descending vessels of an increased draught; at the same time save the expense of enlarging the canals for passing vessels.

To do this blasting, the department have placed a Chain Tag in the rapids, which, if successful in the blasting operations, and in clearing a channel of the desired depth, will be tried as a tow-boat to haul vessels up the rapids. If successful in this, the canals will not require any enlargement, as all navigation will be done in the river; thus saving time and money lost in canaling.

The chain tag was placed in position, August 24, 1876. The chain at the upper end is made fast to Beldon Island, and laid on the bed of the river for one mile below. This mile is only for experimenting with; in event of success it will be lengthened five or six miles.

The chain is of $1\frac{1}{4}''$ iron, weighing $14\frac{1}{2}$ lbs. to the foot run, and was made in England. The tag is very ugly, but very powerful. The engine is of 345 H. P., placed horizontally on two oak keelsons. She has a pair of 22″ cylinders of 60″ stroke, and the pistons connect directly by a simple motion to the "drums," which are two in number, 7′.7″ in circumference each, and take five turns of the chain. The drums are plain with the exception of slots for the inner segments of the upright links of the chain which is held by friction only.

It is worthy of note here, that the chains of the chain tag in the Hochelaga current at Montreal is found to *bind* too tightly, so that it has to be paid out several inches every day. The haul here is very short and straight.

The chain tag at the Galoup is built for blasting, and has six "speeds" or legs of rock elm 14″ square, and 36′ long, which are lowered down through water-tight "speed wells," built in the vessel. Four of these are in the bow, and two in the stern. All of them are used to anchor, but the bow four are used for drilling as well. The drilling is done in a boiler-plate tube at the back of the "speed."

At first the drilling was tried in open water, but the eddies were such that the drills would not strike twice in the same place, notwithstanding the "guide" place was within 12″ of the rock. The rock is about 11′ or 12′ below the surface of the water, and it is intended to blast it away to 16′ below low water.

The rock is hard, crystaline limestone, and is found to dull the drills very quickly.

Nothing of any consequence was done last season as the tag was not finished in time—even after she was placed in position the alterations and improvements occupied some weeks. The only conclusions come to are :—First, It is possible to move her up and down on her chain in the rapid. Second, That it is possible to anchor her anywhere, if her "speeds" or legs will reach the bed of the river (any amount of weight can be brought to bear on the "speeds" by lifting the tag on them). Third, It is possible to drill behind the "speeds" anywhere.

Putting in the charges of glycerine, and setting them off, has not been tried yet. And as a tow-boat she has not been tried. Indeed, it is thought she will not answer for towing, except when the "haul" is straight.

We believe the Department is very much disappointed in her in every way, and it is intended to give her work out by contract; but any way, it is intended during this session of Parliament to decide what is to be done with her.

The experiments with this chain tag have not been full enough (and in this respect are like many other Government experiments) to give a decided opinion concerning her.

REPORTS OF ENGINEERING SOCIETIES

King's College Engineering Society.—At a meeting of this Society on February 9th, a paper on the properties of dynamite was read by Mr. J. C. Mackay, who is now engaged on the works of the tunnel which is in course of construction at Dowlais, Glamorganshire. Mr. Mackay directed attention to the need of a highly disruptive explosive, and at the same time of one available to carry on the arduous operation of the miner with safety and economy. He pointed out that such an explosive should not be affected by damp, should not require large borings, involving expensive work, should not generate an accumulation of smoke, not be too easily ignited, and should possess facility of transport and storage. He showed that dynamite, in careful hands, fulfilled to a great extent all these conditions, and was specially adapted for tunnelling through hard strata of rock. It was not injured by moisture, a quality which no other explosive possessed; it would only explode by detonation, and was not explosive by ignition. It presented an economy in labor which, as compared with other explosives, was in the ratio of 4 to 3. The result of the comparative cost of experiments in Clifton tunnel, for driving fifteen lineal yards, he gave as follows : For powder £29 10s.; for gun-cotton £18 2s.; for dynamite £16 10s. Mr. Mackay also referred to the results obtained by experiments under his own observation at Dowlais, and pointed out, that the use of dynamite must be regulated by the character of the rock, and that though most economical when applied to harder rocks, yet it was found to be less useful in the case of coal and the softer friable rocks. In conclusion, Mr. Mackay referred to the result of the explosions at Hell Gate, as showing the extreme value of dynamite as a submarine explosive. In the discussion which followed, observations were offered by Mr. Douglas, the President, Mr. Alliman, Mr. Compton, and Mr. A. Percy Guinness, the honorary secretary, and a vote of thanks was passed to Mr. Mackay for his interesting paper.—At the meeting of this Society on the 2d ult., a paper on "The Art of Moulding" was read by Mr. E. W. Anderson, A.K.C., hon. member of the Society, and son of one of the members of the well known firm of Eastons and Anderson. The author explained the different methods which are practically used in the art of moulding, and directed attention to the following general rules, which should guide the moulder in the running in of the metal in moulding : 1. Choose if possible the thickest part of the casting for the runner. 2. If the casting is deep, run in the metal at the bottom. 3. Where the casting has a flange in the form of a pipe, it is generally preferred to run the metal in at the flange ; but this case is subject to Rule 4. 4. Where the casting is thin and has many branches, or when it is of great length, it is advisable to run in the metal in the centre. 5. Care should be taken to choose a place in the mould so that the metal will have no tendency to wash any part away in its first rush. 6. (This rule may be called a continuation of No. 5.) The metal should not be allowed to fall from any height upon a weak part of the mould, or it will cause the liability to break down portions of the mould. Mr. Anderson produced several patterns in illustration of the subject to which he referred, and the tools which are used in actual work, which he presented to the museum of the college. The proceedings terminated with a vote of thanks to Mr. Anderson for his interesting paper.

IRON AND STEEL NOTES.

The new Nomenclature in Germany.—We are indebted to the courtesy of James M. Swank, Esq., Secretary of the American Iron and Steel Association, for the following copy of a letter from Dr. Hermann Wedding, of Berlin, on the new nomenclature in Germany:

Berlin, Germany, Jan. 5, 1877.

To the Secretary of the American Iron and Steel Association:

Sir,—Every system has its defects; hence every nomenclature also. The settlement of a system can therefore only be founded upon a compromise, and a system so made is the better the more its nomenclature covers the principal abstracts, and leaves the uncertainties to the lowest divisions. That was my opinion as I put my name under the International Committee's report.

Our ancestors made by the ways of the direct process, or of the charcoal finery, two kinds of forgeable iron, which always differed essentially in the amount of carbon, had, in consequence, essentially different physical properties, and were used for essentially different purposes. The intermediate kinds of iron were not in use, and were therefore not purposely produced. The puddling process originated at first an intermediate product, the so-called "fine-grained iron."

All these products were obtained in a pasty state. Now comes the Bessemer process and produces a fluid, forgeable metal, and several adjoining processes do the same. Fluid irons are now easily made of different amounts of carbon, and every intermediate product is blown without difficulty. From this time the property of hardening no more stands in the foreground; it goes back, and the properties which are a consequence of the fluid state take the leading place. At the same time arises the necessity of a new nomenclature.

The nomenclature of the International Committee is known. Let me show the system:

Iron.	Forgeable; difficult to melt: Forgeable iron. I.	Obtained in a fluid state: A. Ingot iron.	Hardening: 1. Ingot steel.
			Not hardening: 2. Ingot iron.
		Obtained in a non-fluid state: B. Weld iron.	Hardening: 3. Weld steel.
			Not hardening: 4. Weld iron.
	Not forgeable; easy to melt: Pig iron. II.	With amorphic carbon only: C. White pig.	
		With graphite: D. Gray pig.	

There may be added, called as before: *Remelted* pig iron—cast iron; *remelted* steel of every description—cast steel. Here the division following the fluid or non fluid state keeps the principal place; the hardening only the second. Therefore, all the members of the Committee, differing in some points (Mr. Akerman and myself wishing a more detailed subdivision), agreed to this compromise without hesitation.

It is asserted that such a compromise, comprising the languages of the principal iron-producing peoples, has not been necessary, and that each country may keep its own expressions without caring about others. But how can that be good and useful? I think every one, Protectionist or Free Trader, must be a friend of clear and distinct definitions, whether in treaties of commerce or in simple tariffs. And even besides this international question, is it not necessary for the public trade to have accurate definitions for every kind of ware, giving no room for intentional or unintentional deceptions?

By the new nomenclature accepted and introduced, every tradesman and every customs' officer who knows nothing about iron metallurgy easily distinguish: I and II by the forgeability; C and D by the color; A and B by the fracture—if necessary, by an easily made etching with acid; 1, 2, 3 and 4 by the hardening. Also, those ought to be satisfied who desire to examine the chemical properties, viz.:

Iron.	I. contains O 2, 3°° C.	2 and 4; O-O, 6°° C.
		1 and 3; O, 6 2, 3°° C.
	II. contains 2, 3-5°° C.	Amorphic C.
		Graphitic and amorphic.

But it is not necessary to make analysis, and to dwell upon differences growing from the presence of other matters, which would be the case if you classify according to the amount of carbon.

After having read all that has appeared in your *Bulletin* and *The Engineering and Mining Journal*, I have no hope that our nomenclature will be accepted in America. But let me tell you, we are happier! It may be the interior value of the nomenclature, or it may be the authority of the names of the international committee, that has accomplished the result; but what long discussion could not do is done! The nomenclature *is* accepted in Germany.

The professors of iron metallurgy in Germany, Austria and Hungary have accepted it; the most widely-circulated journal of mining and metallurgy and the official journal of the ministry of trade and commerce have accepted it; the Association for the Progress of Industry at Berlin and the Association of Miners and Smelters at Karntnen, have accepted it. It will be introduced very probably in all official statistics. So we are certain that at least our rising generation will unanimously use the nomenclature proposed by the international committee.

Well, you Americans will of course do what you think best; but please accept our German thanks, added to many thanks for the kind and amiable reception given us in your wonderful country, that you again have been the best help to a uniform nomenclature of iron in Germany. Very truly,

Dr. Hermann Wedding.

RAILWAY NOTES.

Fracture of Railway Tires.—At a meeting of the Institution of Civil Engineers, in November, a paper was read on "The Fracture of Railway Tires," by Mr. W. W. Beaumont, of which the following is an abstract:

It was stated that between the years 1847 and 1874, eighty accidents from broken tires, attended by serious results, had been reported upon by the officers of the Board of Trade. The total number of tires fractured was not known, as previous to 1872 the railway companies made no return of such accidents; but, since 1847, tire fractures had resulted in the loss of seventy-four lives, and 236 cases of serious personal injury. So far as the author was aware, no satisfactory explanation had been given of the forces productive of fracture of tires of good material and workmanship; it was the object of this paper to suggest a cause for their origin. Some of the theories advanced to account for tire fracture were treated of, such as the strain due to shrinking tires on to wheel bodies, the reduction of the sectional area by rivet or bolt holes, and the alleged reduction of the strength of the tire by low temperatures in winter. These causes were considered to be inadequate to account for—(1) The fracture of a good tire; (2) the fracture of tires in several places simultaneously; (3) the fracture of tires through the solid body rather than through bolt or rivet holes; (4) breakages being few in number for a long period, and then occurring frequently; and (5) tires, generally of considerable age, running several thousand miles before flying to pieces.

For an explanation of these facts, the author appealed to internal differential molecular strains, generated in the material of tires, by extension and compression from their surface inwards, consequent upon their rolling at high velocities under heavy loads, along the hard, smooth and somewhat rigid permanent way. If a piece of flat stout plate metal was subjected, when cold, to long-continued light hammering, or rolling, on one of its surfaces, that surface would become compressed and elongated. The effect of thus altering the relative dimensions of the two surfaces of the originally flat plate, would be to make it assume the form of an umbo, with the convexity toward the rolled or hammered surface. In illustration of this, reference was made to the straightening of coping plates, or other plate castings, which had become bent in cooling, by lightly hammering the concave side and thus elongating that side. Another example was afforded in the curvature produced in tram plates, for instance, those on Westminster Bridge, by the extension and compression of the surface exposed to the rolling under the loaded wheels of vehicles. Similarly, film after film from the surface inwards of the material of a railway tire was compressed, until the thickness molecularly altered, induced internal differential strains sufficient to rupture the tire, or so nearly to effect it, that an unusually heavy impulse, or other extraneous force, was alone necessary for such a result. As these strains approached equality throughout the tire, the length, and therefore the number of pieces into which the tire would be broken, would be determined by the limit of stability and the coefficient of elasticity of the material. Absolute simultaneity of multiple fracture was not a necessary condition of such a result, as the precedence of one fracture would liberate the tire, so that the internal forces would be free to initiate fracture in as many places as might be necessary to expend the excess of the forces tending to rupture, over those of resistance to it. Of the reported fracture of tires, affixed by rivet, or screws, nearly one-third were fractured through the full section, and not at a bolt or rivet hole; thus indicating that those tires were either strongest at the reduced section, or that the internal forces tending to produce fracture were greater between than at the rivet or bolt-holes. In tires of good material and workmanship, fracture would be expected to take place rather between than through such holes; for at these the continuity of the material was broken, so that the tangential compression, produced in the outer portions of the tire by the impeded elongation of the material, was dissipated by an upward flow of the particles around such holes. This upward flow tended to produce a crater-like ridge, which was quickly worn off, so that the tire at these points was relieved of strain, the material that would have exerted it being carried away. Elastic wheels could only be considered as a palliative, for the tire had still to support a load, so that its surface would be subject to compression, although the mischief would not proceed so rapidly as with a nearly rigid wheel. The inertia of impact strain upon a rigid wheel would have to be overcome by the tire before it was relieved by the springs of the vehicle, whereas a good elastic wheel possessed in some degree the character of a spring, and in so far was without any such inertia. However good the material and workmanship of a railway tire, and in whatever manner affixed, it must gradually become unsafe, from other reasons than simple loss of thickness, for whether it was of steel or of iron, it was amenable to the production and accumulation of molecular strains. The great durability of American chilled wheels was probably owing to the extreme hardness of their running surfaces, and their consequent resistance to surface compression. Although the ultimate strength of a tire was probably not reduced by the bolt or rivet holes, the preferable method of fastening was unquestionably by continuous clips and grooves on both sides of the tire, so as to prevent the portions of a fractured tire from leaving the wheel. It was to this latter cause, rather than to simple fracture, that many lamentable accidents were to be ascribed.

RAILWAY-BRAKE EXPERIMENTS.—Important experiments with railway brakes commenced recently on the Edinburgh and Glasgow section of the North British Railway. Amongst the gentlemen present to assist in the experiments there were official representatives of railway companies in all parts of the kingdom.

The train, with which the first series of experiments was made, consisted of a locomotive engine and tender, eight carriages and two vans, the whole weight of which was about 155 tons, exclusive of probably fifty persons, who may be taken as averaging at least 12 stones, or 1½ cwt. each; and the continuous brake system applied to the train, was that known as the Westinghouse automatic, which we previously described. All the wheels of the train were "braked," with the exception of those of the bogie on the front part of the engine, and those of the van in which the results of the experiments were observed and recorded; and the arrangements were of such a character that the brakes could be applied throughout the whole of the train, either from the engine or the recording van separately, or from both, at the same instant of time. The van alluded to, a spacious covered vehicle, capable of accommodating fully a score of people, was set apart for the use of the ingenious apparatus previously spoken of as the Westinghouse train-speed indicator. Messrs. Stirling, Haswell, Cowan, and Wright, with the assistance of Mr. Drummond, North British locomotive superintendent, were a committee for determining the experiments to be performed.

When everything was announced to be in readiness, the train left the Waverly Station, Edinburgh, at about a quarter past nine o'clock, on the run to Glasgow. On the westward run between Edinburgh and Cowlairs, there were eleven applications of the brakes when the train was running at speeds ranging from thirty up to sixty miles per hour, as shown by the speed indicator. As a rule, the experiments were not made at first with that amount of reliability that was desirable, and several of them were not taken into consideration in officially recording the results. Up to the time when the train had passed Linlithgow Station, it had never attained a speed of more than fifty-five miles per hour, and the greatest speed—sixty miles an hour—was attained when the train was passing Woodilee Asylum, Lenzie. One stoppage was effected in twenty-eight seconds, when the speed was fifty-four miles an hour; at another time a complete standstill was attained in twenty-nine and a half seconds, when there was a speed of sixty miles an hour on the train.

After stopping some time at Cowlairs, where the party was largely increased, shortly after eleven o'clock a return journey to Edinburgh was made, the recording van being the last vehicle in the train. In running what was called the "up express" no fewer than eighteen experiments were made. Between Cowlairs and Polmont, there were ten stoppages while the train was running at speeds varying from thirty to sixty miles per hour, the complete stop being secured in periods ranging from ten and a half seconds up to twenty-seven seconds. The eleventh stoppage was done in twenty-four and a half seconds, when the speed was at sixty miles an hour. A later stoppage, some distance eastward of Winchburgh, when a speed of forty miles an hour had been attained, was effected by applying the brakes from the van alone, and without any communication with the engine-driver. A dead stand was attained in thirty and a half seconds. In this case the engine was not, we believe, brought to bear in the stoppage of the train, and hence the longer time required to secure the stoppage. Another experiment of a similar sort was made when the speed was indicated at forty-five miles an hour, and complete rest was got in thirty-four and three-quarter seconds. Lastly, just as the train approached the Edinburgh Station, the brakes were applied when the speed was forty miles an hour, the application being made simultaneously in the van and on the engine. The stop was effected in nineteen and three-quarter seconds.

During the progress of the experiments, no cognizance was taken of the distance over which the train ran from the moment of applying the brake-blocks to the wheels and the complete stoppage; but from the results obtained, the distances will in due time be worked out from tables constructed for the purpose. Under ordinary circumstances a train-speed of sixty miles an hour should be perfectly overcome in about 300 yards, or 900 feet.

Experiments with Smith's vacuum brake will take place on another occasion.—*Iron.*

ENGINEERING STRUCTURES.

NEW ENGINEERING DEVICE.—A peculiar work has been completed by the Ches. & Ohio Canal Company to make a new outlet from the canal to the Potomac. The elevation to be overcome is forty feet, which under the old system would require eight locks and nearly an hour's time for the passage. The new arrangement is the employment of a large caisson, or tank, filled with water, into which the boat is floated, when the caisson, with its load of water and boat, is run down the incline on rails in less than six minutes. The weight of the loaded caisson is about 350 tons. The first expense of constructing locks and the constant expense of operating them and keeping them in repair is saved, as well as the time.—*Railway Review.*

NEW DEVICE FOR RAISING WATER.—M. Th. Foucalt has recently produced a new apparatus for raising water by means of ammoniacal gas. The machine depends for its operation on the facts that water at 15 deg. Cent. absorbs 743 times its volume of ammoniacal gas, and gives it off again at 60 deg. Cent.; that at 100 deg. Cent., the tension of the vapor is seven and a half atmospheres; that petroleum and ammoniacal gas are without action upon each other; and that the same is true of petroleum and water. The apparatus consists substantially of a heater, which is partially filled with a strong aqueous solution of ammoniacal gas.

This heater is connected by pipe with the upper part of a closed reservoir, the lower part of the reservoir being connected by means of pipe and suitable valves with the steam or well from which, and the tank to which, water is to be raised. The reservoir contains a small quantity of petroleum, which forms a thin stratum on the surface of the water, and serves to keep the ammoniacal gas from contact with it, and, as the inventor expresses it, forms a fluid piston. The operation is as follows: Supposing the reservoir full of water, the temperature of the heater is raised by suitable means, ammoniacal gas is given off, and passes over into the upper part of the reservoir, the stratum of petroleum preventing its being absorbed by the water there. A pressure is thus created in the reservoir, which forces the water there out and up to the tank to be filled. When all the water has been forced out of the reservoir, the heater is cooled by removing the fire and allowing a jet of water from the tank to play on it. The water in the heater, as it cools, re-absorbs the ammoniacal gas from the reservoir, and thus creates a vacuum, which the water from the stream or well rushes up to fill, and thus refills the reservoir. The heater is then heated, and so on, as before. The inventor claims that the consumption of fuel is almost insignificant as compared to that of a steam-pump of the same capacity. The author also describes a modification of his apparatus adapted to be run by the heat of the sun, in which case the only expense is that of wear and tear, which is small, there being no moving parts.

EGERTON'S TIDAL PIER.—When Mr. Egerton brought out the ship built on pontoons, which we noticed some time ago, he was met, among other objections, with the difficulty of providing a sea pier which would permit of trains being run at the varying levels of the tide direct on board. This objection he set himself at once to meet, and last week he exhibited to various engineers and other persons interested in the matter a model of a very ingenious pier, built in sections, and apparently very well contrived for its special object. The connection between the shore and the floating pier, instead of being supported by continuous girders, is made up of a number of short sections, supported by pontoons at the points of connection. The pontoons are set in guides, and in the case of seaports a breakwater may be added to protect them against excessive motion by the waves. The actual support which connects each pontoon with the roadway is a kind of gigantic "lazy tongs," which "gives" to exactly the extent needed. In the model, high and low water was produced by adding and drawing off water as needed; and, however great the change in level, a perfectly straight though not rigid road is maintained. A railway train could thus, the inventor claims, be run on to a vessel, be carried across an arm of the sea—or the Channel itself—and be run on shore again, so as to travel from London to Paris without change of carriage. But lest this be considered too great a task, it should be mentioned that this pier is equally adapted for smaller achievements. It is suggested as good means of attracting traffic below bridge on the Thames, and of improving the communication between Liverpool and Birkenhead, and other places similarly situated. The principle can easily be applied to existing piers, and may be readily arranged in such a manner as to suit any spot where it may be required. It can be placed either at right angles to the shore line, parallel to it, or at any desirable angle. It may be constructed with any number of supports, with one or any number of pontoons, with one or any number of girders, and of any strength which may be considered necessary.

The advantages claimed for the invention are as follows:—(1) A great saving in the cost of transporting goods across all such rivers as the Thames (below bridge), the Mersey, etc. (2) A very strongly-marked relief to the overwhelming traffic of the city of London. (3) A most important saving in time and expense in conveying railway trains, direct and intact, from one side of a tidal river or arm of the sea to the other. (4) A great saving in the construction of both piers and approaches as compared with those at present in use.—*Iron.*

ORDNANCE AND NAVAL.

A NEW BREECH-LOADING GUN.—However great may be the difference of opinion among artillerists concerning the relative merits of breech and muzzle loading guns, it will, we think, be readily conceded that Sir William Armstrong and his partners deserve great credit for the perseverance with which they have attacked a very abstruse mechanical problem. It would seem that they have at last achieved a real success; in other words, the firm have recently turned out a breech-loading gun weighing forty tons, or thereabouts, which appears to be free from the prominent defects of all other breech-loading ordnance. The new gun is constructed on the coil principle and has a bore of 12 inches. The weight of the servile projectile is 700 lbs., propelled by charges of from 160 lbs. to 170 lbs. of pebble powder. The breech is closed by a screw in a way very similar to that adopted by French artillerists, and described and illustrated in our columns. The breech screw is cut away by channels slotted through the threads, and the worm in the breech of the gun is similarly treated. To close the breech the screw is entered in such a way that the threaded portion meets the slots in the gun, the threaded part of the gun in like manner taking the slots in the screw. A turn of one-sixth of a revolution interlocks the threads and makes the breech secure. The gas check consists of a steel saucer, resting on a slightly convex surface on the inner end of the screw. The edge of this saucer is forced against a small rebate in the gun, and by setting up the screw it is made to take a firm bearing against this rebate; when the screw is released the cup contracts by its elasticity, and comes out with the screw with perfect facility. The screw is supported on a hinge, and can be swung back out of the way when the breech is opened. It is easily worked by one man. The projectile is at once made gas-tight, and given its motion of rotation by a copper ring hooped round the base of the shot, which ring is upset into the grooves when the powder is ignited. Several guns have already been made, but of small size, on this principle at Elswick, but the forty ton gun is the first of its size. It has just been tested at the Elswick proof ground, some forty miles north of Newcastle, in the presence of all the leading artillerists of the day. The gun was fired several times with charges varying from 160 lbs. to 180 lbs., the initial velocity being very high, reaching as much as 1,615 feet per second, representing an energy of over 12,000 foot-tons. The experiments were perfectly successful in every respect. Of course only prolonged firing can demonstrate the powers of endurance of the new gun, but there is every reason to believe that these will prove sufficient for every necessary purpose.

Foreign Navies.—The Navy Department of Turkey is one of the eight ministerial departments of the Divan. The two largest ironclads are the sister ships Mésondivé and Mendonhijé, launched in 1874. They are 9,000 tons displacement, have a main deck battery of twelve 18-ton guns, projectile 400 lbs. The forward and after ports of the casemate are cut at an angle, so as to answer for bow and stern chases. The casemate is of 12-inch iron, and the hull is protected by 12-inch belt, the deck forward and abaft the casemate being shell proof. The spur is of unusual strength and below water. Two 6-ton guns on forecastle, fire directly ahead, one gun abaft of same calibre, fires directly astern. On spar deck are six 20-pounders, probably for saluting—total 21 guns. The Azizieh, 900, 16 guns; the Orkanieh, 900, 16 guns; the Mahmoudieh, 900, 16 guns; the Osmadieh, 900, 16 guns; and the Athor-Terfik, 750, 8 guns. There are also five ironclad corvettes carrying four or five guns each, and the two monitors, Hejzie-Rahman and the Loufan Djelil, carrying two 150-pounders each, and two light guns. The twin-screw ironclads Aoni Illah (Help of God) and Muin Taffer (Aid to Victory) are sister ships of 1,400 ton armor, five and a half inch. Four 12-ton rifle Armstrong guns, 250-pounders, are mounted in a central battery, so arranged as to admit being fired ahead or astern. These two vessels are said to possess very high rate of speed.

Following the above paragraph the appended information will be read with considerable interest. A correspondent of the Times, writing on the condition of the Russian ironclads, says, with regard to the Peter the Great: "She is so weak that if driven through the water at a speed greater than eight knots she shakes to such a degree as to leak in an alarming manner. Although the extent of her longest voyage is the distance between Cronstadt and Revel, her boilers are already under repair, and a commission which was lately assembled to examine her has expressed an opinion that all the large steam pipes should be renewed. As to her present capabilities for either offensive or defensive purposes, it is sufficient to say that when her heavy guns are fired rivet heads fly about unpleasantly. I think I have said enough about this ironclad, the pride of the Russian Navy." He goes on to say: "Now a few words with regard to the Popofkas. It is literally dangerous to fire the guns on board them. During a recent gun practice on board one of them, near Otchakof, the following results were obtained: At the first round almost every man on board was knocked down; the whole of the super-structure on deck was blown away, and the deck itself, which is iron-plated, was considerably bulged in a downward direction. I here beg to remark that the accuracy of the statements contained in this letter can be easily tested by any one who will take the trouble to make the necessary inquiries in this capital (St. Petersburg)." Mr. E. J. Reed in commenting upon the statements of this correspondent, says:—"He gives as a consequence of ordinary gun practice in the circular ship near Otchakoff, what I do not hesitate to pronounce a very exaggerated statement, and he refers me to St. Petersburg for proofs. But being already in possession of the facts, I am able to speak in the above terms of his statement and to add that the blowing down of some bulkheads in the superstructure and the depression of part of the deck were consequences of a most unusual accident, the gun having been fired by oversight over an open hatchway which ought to have been closed during gun practice. The natural consequences ensued."

The Dreadnought, double turret-ship, went out of Portsmouth Harbor recently, for a preliminary trial under way of her machinery, which was under the sole control of Mr. Robert Humphrys, of the contracting firm. Everything passed off with the greatest success. The blast was not once used, nor was it considered necessary to remove the ashes to increase the draught. The engines easily realized sixty-nine revolutions a minute, while the power developed was considerably over the contract power of 8,000 horses. The speed obtained was about fifteen knots an hour. The ship was so sensitive that she readily obeyed the slightest touch of the helm. On Friday, 5th Jan., the six hours' trial was made, in very boisterous weather. The wind blew strongly from the south-west, and at one time such banks of fog and rain clouds rose from the Isle of Wight and spread themselves over the sea that it appeared as if the trial would have to be postponed. There was some difficulty experienced in catting the anchor, in consequence of the carrying away of a ground chain; but the anchor was placed on the bill-board by about ten o'clock, and the ship got under way from Spithead at once. The wind had increased somewhat in the meantime until at its highest it blew with the force of from six to seven. The Island, however, acted as a capital breakwater, and the runs were confined within the Nab. In running up and down the measured mile course the ship was on several occasions timed, when it was found that a mean speed of 14½ miles had been obtained. This was highly satisfactory, but even better results will be obtained when the mile trial is made. The draught of the ship on Friday, 6th Jan., was only twenty-one feet eleven inches forward and twenty-four feet six inches aft, whereas her estimated load draught when ready for sea is twenty-six feet eight inches forward, and twenty-seven feet two inches aft, or rather more than the immersion of the Thunderer. As the trial was not only for the purpose of enabling the contractors to obtain the covenanted horse-power out of the engines, but also for the purpose of ascertaining the consumption of coal in proportion to power, the boilers were easily fired in order to keep down steam. This was rendered all the more necessary in consequence of the boisterous character of the weather, for no sooner did the ship give a lurch or indulge in a roll, which she did whenever she went about, than the spring safety-valves lifted, and the steam escaped with a rush. With smooth water, consequently, it is very probable that even better data would have been obtained.

BOOK NOTICES.

The Chemist's Manual. By Henry A. Mott, Jr., E.M., Ph.D. New York: D. Van Nostrand. Price $6.00.

This work is an accumulation of practical notes designed to afford to the chemist a ready reference book of sufficient scope to serve any ordinary needs. To this end the author has skillfully arranged his work into the several departments of Qualitative Analysis; Mineralogy; Quantitative Analysis; Assaying; and in addition a Miscellaneous Department, which contains all tables in common use by the chemist. The test of practical utility seems to have been the only one applied by the author in selecting materials for the work.

A brief preface by Prof. Chandler, thus endorses the book:

"This carefully prepared manual of Dr. Mott will prove especially valuable, as containing a judicious selection of the most important methods, most of which have been tested by laboratory experience, and found to give satisfactory results. These are presented in concise form with reference to original authors. The numerous tables of constants will also be found of great value.

"This work will possess a special value for the student and laboratory worker, and will serve as a useful reference book for the general scientific reader."

Electricity and the Electric Telegraph. By Geo. B. Prescott. New York: D. Appleton & Co. For sale by Van Nostrand. Price $5.00.

The author aims in this work to present an accurate and comprehensive summary of Electricity and Telegraphy.

No pains have been spared in the way of illustration to render the author's descriptions perfectly clear.

In addition to explanations of all systems of Telegraphy worth describing, a complete compend of the laws of practical Electrical Science are carefully and logically presented.

The author's previous work was widely read, and served for a long time as the best known reference book on telegraphic systems. It enjoys yet a reputation which technical books rarely enjoy, of being readable. The present work is designed to take its place; it is fuller of scientific description and essay, but we doubt not will be as widely appreciated.

A Text-Book of Mineralogy. By Edward Salisbury Dana. New York: John Wiley & Son. 1877. Price $5.00.

The preparation of a text-book on mineralogy was begun several years since by Prof. J. D. Dana, but the state of his health compelled him to relinquish it. The author of the work before us assumed the editorship, and completed the work substantially on the original plan.

The work is intended to meet the requirements of class instruction. It is presented in three divisions or Parts. Part 1 is devoted to Physical Mineralogy, and is subdivided into Crystallography and Physical characters of Minerals. Part 2 presents Chemical Mineralogy, and Part 3 Descriptive Mineralogy. This latter portion is only an abridgement of Dana's System of Mineralogy, which is known wherever there is any interest in the subject.

The chemical formulas are of the new system. The section on Crystallography is after the method of Naumann, and is an elaborate presentation of the subject. A colored plate of polarization phenomena embelishes this very complete book.

The Elements of Machine Design. By W. Cawthorn Unwin. London: Longmans, Green & Co. 1877. For sale by D. Van Nostrand. Price $1.50.

This is an introduction to the principles which determine the arrangement and proportions of the parts of machines, and a collection of rules for machine design.

So far as the principles contained in this book have been expounded before, it has been as a part of Applied Mechanics.

The topics treated by chapters are in order as follows: Materials of Construction; Straining Actions; Resistance of Structures to Straining Actions; Riveted Joints; Fastenings; Pipes and Cylinders; Journals, Pivots, etc.; Bearings for Rotating Pieces; Toothed Gearing; Belting; Rope Gearing; Linkwork; Pistons, Valves, and Cocks

The book is the latest addition to the series of text-books of science.

Elements of Chemical Physics. By Josiah P. Cooke, Jr. Third edition. Boston: John Allyn. For sale by D. Van Nostrand. Price $5.00.

This is doubtless the best work in Chemical Physics in the English Language. It is well-known to chemists everywhere, and the pages of former editions have afforded the best materials for the construction of our modern text-books for students.

There is no claim of any addition or improvement upon the former edition, and so far as we know, none was called for to meet the demands of scientists.

A reduction of this work to smaller dimensions formed the well-known Chemical Philosophy by the same author.

General Report of the Minister of Public Works of Canada, for the Fiscal Year ending June 30th, 1876. Ottawa: Maclean, Roger & Co.

This is of the public document variety of literature, and is not widely different from the others of its kind.

The information contained is rather of the geographical and commercial order of statistics, than of the engineering kind. A very useful map is folded in the report.

The Combined Note-Book and Lecture Notes, for the use of Chemical Students. By Thomas Eltoft, F.C.S. London: Simpkin, Marshall and Co. 1876.

There are so many helps for chemical students that we are almost at a loss to imagine why there should be another. The present work does not afford us any great amount of assistance in making a conjecture. It reminds us strongly of Frankland's "Lecture Notes," interleaved with blank pages, and really contains little which is not already in that useful text-book. However, that which suits one man does not always suit another, so doubtless some will prefer the work before us; and for the benefit of these a little more care will be well bestowed upon the next edition, both as to clearness and consistency of expression, as well as to printing.

Dynamics or Theoretical Mechanics. By J. T. Bottomley, M.A., &c. London: Collins, Sons & Co.

This handy work is one of the Messrs. Collins' well-known elementary science series, and although not very voluminous, contains a mass of information in a neat and comprehensive form. In a short introduction the learned author (who, by the way, has lectured and demonstrated in natural philosophy in the Glasgow University) explains the meaning of the word dynamics, which of late had been incorrectly included in the term mechanics. "Dynamics," he says, "or the science which treats of force and its effects in general, is subdivided into two branches, to which the names Statics and Kinetics are given. Statics is the branch which treats of the balancing of forces. . . . Kinetics is the part of dynamics which treats of forces acting against inertia of matter." On this joint basis he continues his work through eight well-written and highly instructive chapters, and in conclusion gives a number of exercises and some tables of comparison of British and metrical measures. No student in this branch should be without this work.

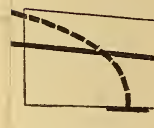
Science Lectures at South Kensington: Outlines of Field Geology. By Professor Geikie, LL.D., F.R.S.; The Absorption of Light and the Colors of Natural Bodies. By Professor Stokes, F.R.S. London. 1876. For sale by D. Van Nostrand. Price 20 cts.

Whatever opinions may be held as to the expediency of continuing the lecture department of the late Loan Exhibition at South Kensington, there can be but one as to the excellence of many of the discourses there delivered. The two lectures by Professor Geikie form a case in point. They give, with admirable clearness and with commendable brevity, a complete outline of their subject, calculated to serve as a valuable aid either to the student who wishes to become a practical geologist or to the teacher who desires to show his pupils how they may learn in the open air. Professor Stokes' two lectures on absorption and fluorescence are precisely what might have been expected from a master of subjects which he has made his own, and they can be recommended as excellent, if brief, monographs upon certain points of the science of light.

MISCELLANEOUS.

Cleveland Ironmasters' Return.—These monthly returns were issued lately. They show 108 furnaces blowing, as against 112 in Sept., 1875; 55 out, as against 47 in September, 1875: and four as being the increase in the number erected since September.

M. Leclanche has just constructed a new galvanic battery, which the *Annales Industrielles* thinks likely to render great service both in manufactures and in scientific research. The original oxide of manganese battery by the same inventor consists of a porous jar filled with pyrolusite, in which is contained the carbon forming the positive pole. This jar is immersed in a solution of sal-ammoniac in contact with zinc. M. Leclanché has, however, introduced several improvements into this battery. He has superseded the porous jar by conglomerating the oxide of manganese, mixed in nearly equal parts with carbon, but with the addition of a small quantity—five per cent.—of resin for the purpose of giving consistency to the mass. These three substances, properly pulverized and intimately mixed, are conglomerated under a considerable pressure, and at a temperature of about 100 deg. Cent.—212 deg. Fah.—into a solid cylinder, which serves at the same time as a porous diaphragm and a positive electrode. But here a difficulty occurred. Under the influence of the current, an almost insoluble oxychlorate of zinc was formed, which was deposited in a crystalline form in the pores of the electrode, and considerably diminished its conductibility, so that the internal resistance of the battery increased very rapidly, occasioning considerable inconvenience, especially when used for telegraphic purposes. M. Leclanché has now got rid of the difficulty by inserting in the center of the carbon and manganese electrode, while being moulded, a small cylinder of bisulphate of soda. This acid salt prevents the formation of the oxychlorate of zinc; and the battery preserves its regularity for more than a year without the necessity for renewing the water of the saline solution. It offers a much slighter resistance than other batteries, and gives out a considerable quantity of electricity. A single element of small size, presented by M. Du Moncel to the Academie, immediately caused a platinum wire connecting its two poles to become red hot.



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VAN NOSTRAND'S

ECLECTIC

ENGINEERING MAGAZINE.

NO. CI.—MAY, 1877.—VOL. XVI.

NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

V.

THE CINCINNATI AND COVINGTON SUSPENSION BRIDGE. (Fig. 10.)

THE main span of this bridge has a length of 1057 feet from center to center of the towers, and the side spans are each 281 feet from the abutment to the center of the tower. The deflection of the cable is 89 feet at a mean temperature, or about 1—11.87th of the span. There is a single cable at each side of the bridge. Each of these cables is made up of 5200 No. 9 wires, each wire having a cross-section of 1-60th of a square inch and an estimated strength of 1620 lbs. Each of these cables has a diameter of $12\frac{1}{3}$ inches, and an estimated strength of 4212 tons. Each cable rests at the tower upon a saddle of easy curvature, the saddle being supported by 32 rollers which run upon a cast iron bed-plate 8×11 feet, which forms part of the top of the tower. Since the bed-plate is horizontal this method of support ensures the exact perpendicularity of the force which the cables exert upon the towers, without its being necessary to make the inclination of the cable on both sides of the saddle the same. There is, therefore, no tendency by the cables to overturn the towers, and they need only be proportioned to bear the vertical stresses coming upon them.

As this bridge differs greatly in some respects from other suspension bridges, it seems necessary to describe its peculiarities somewhat minutely.

The roadway and sidewalks make a platform 36 feet wide, extending from abutment to abutment, 1619 feet. It is built of three thicknesses of plank solidly bolted together, in all 8 inches thick. This is strengthened by a double line of rolled I girders, 1630 feet long, running the entire length of the center of the platform. These I girders are arranged one line above the other, and across between them, at distances of 5 feet, run lateral I girders which are suspended from the cable. The upper line of girders is 9 inches deep, (and 30 lbs. per foot); the lower line is 12 inches deep (and 40 lbs. per foot). The lateral girders are 7 inches deep (and 20 lbs. per foot), and are firmly embraced between the double line of longitudinal girders. The girder of this center line are each 30 ft. long, and are spliced together by plates in the hollows of the I but the holes through which the bolts pass are slots whose length is two or three times the diameter of the bolts. This

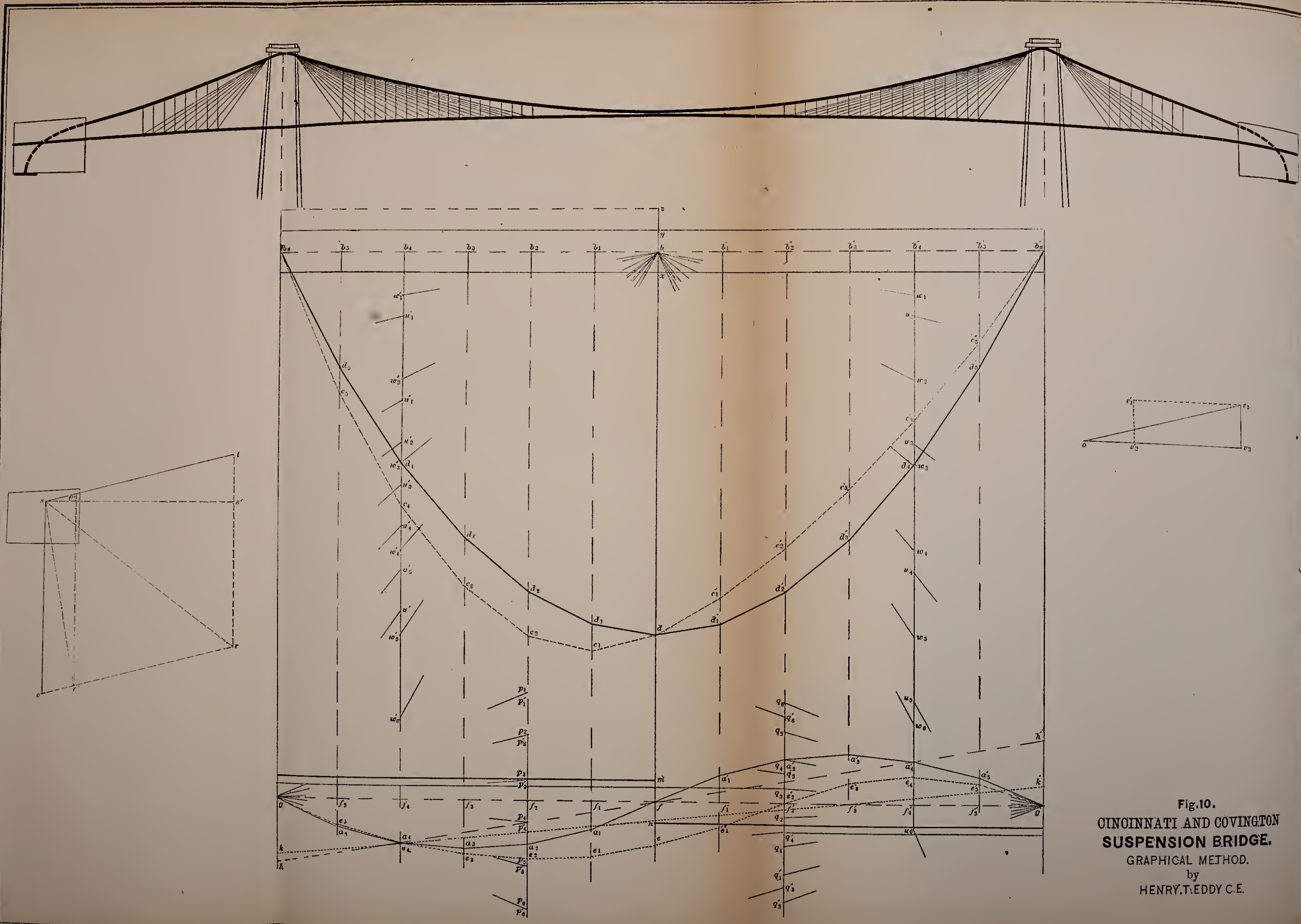


Fig.10.
CINCINNATI AND COVINGTON
SUSPENSION BRIDGE.
GRAPHICAL METHOD.
by
HENRY T. EDDY C.E.

makes a "slip joint" such as is often used in fastening the ends of the rails on a railroad. The slip joints permit the wooden planking of the roadway to expand and contract from variations of moisture and temperature without interference from the iron girders which are bolted to it.

There is also a line of wrought-iron truss-work about 10 feet deep extending from abutment to abutment on each side of the roadway, consisting of panels of 5 feet each, to each lower joint of which is fastened a lateral girder and a suspender from the cable. This trussing is a lattice with vertical posts and ties extending across two panels, and its chords are both made with slip joints every 30 feet.

It is apparent that this whole arrangement of flooring with the girders and trusses attached to it possesses a very small amount of stiffness, in fact the stiffness is principally that of the flooring itself. It will permit a very large deflection, say 25 feet, up or down from its normal position without injury. Its office is something quite different from that of the ordinary stiffening truss of a suspension bridge. It certainly serves to distribute concentrated loads over short distances, but not to the extent required, if that were the sole means of preserving the cable in a fixed position under the action of moving loads. Its true function is to destroy all vibrations and undulations, and prevent their propagation from point to point by the enormous frictional resistance of these slip joints. When a wave does work against elastic forces, the reaction of those forces returns the wave with nearly its original intensity, but when it does work against friction it is itself destroyed.

The means relied on in this bridge to resist the effect of unbalanced loads is a system of stays extending from the top of the tower in straight lines to those parts of the roadway which would be most deflected by such loads. There are 76 such stays, 19 from the top of each tower. The largest stays extend so far as to leave only 350 feet., *i.e.*, a little over one-third of the span, in the center over which they do not extend. Each stay being a cable $2\frac{1}{4}$ inches in diameter has an estimated strength of 90 tons. They are attached every 15 feet to the roadway at the lower joints of the trussing, and are kept straight by being fastened to the suspenders where they cross them. This system is shown in Fig. 6 in which all the stays for one cable are drawn together, with every third suspender. The suspenders occur every 5 feet throughout the bridge but none are shown in the figure except those attached at the same points as the stays.

These stays must sustain the larger part of any unbalanced load, at the same time producing a thrust in the roadway against either the abutment or tower.

It is really an indeterminate question as how the division of the load is made between the stays and trussing; and this the more, because of the manner in which the other extremities of the stays are attached. Of the nineteen stays carried to the top of one tower, the eight next the tower are fastened to the bed plate under the saddle, and so tend to pull the tower into the river; the remaining eleven are carried over the top of the tower, and rest on a small independent saddle, beside the main saddle, and are eight of them fastened to the middle portion of the side spans as shown in Fig. 6, while the other three are anchored to the abutment.

In view of the indeterminate nature of the problem, it has seemed best to suppose that the stays should be proportioned to bear the whole of any excess of loading of any portion of the bridge, over the uniformly distributed load (which latter is of course borne by the cable itself); and further that the truss really does bear some fraction of the unbalanced load, and that the bending moments have therefore the same relative amounts as if they sustained the entire unbalanced load. This fraction, however, is quite unknown owing to the impossibility of finding any approximate value of the moment of inertia I for the combined wood and iron work of the roadway.

This method of treatment has for our present purpose this advantage, that the construction made use of is the same as that which must be used when there are no stays at all, and the entire bending moments induced by the live loads are borne by the stiffness of the truss alone.

Now in order to determine the tension

in any stay, as for instance that in the longest stay leading to the right hand tower, lay off v_1v_2 equal to the greatest unbalanced weight, which under any circumstances is concentrated at its lower extremity. This weight is sustained by the longitudinal resistance of the flooring, and the tension of the stay. The stresses induced in the stay and flooring by the weight, are found by drawing from v_1 and v_2 the lines v_1o and v_2o parallel respectively to the stay and the flooring. Then v_1o is the tension of the stay, and that of the other stays may be found in a similar manner.

It is impossible to determine with the same certainty how the stress ov_2 parallel to the flooring is sustained. It may be sustained entirely by the compression it produces in the part of the flooring between the weight and the tower or the abutment; or it may be sustained by the tension produced in the flooring at the left of the weight; or the stress ov_2 may be divided in any manner between these two parts of the flooring, so that v_1v_1' may represent the tension at the left, and ov_2' the compression at the right of the weight. It appears most probable that the induced stress is borne in the case before us by the compression of the flooring at the right, for the flooring is ill suited to bear tension both from the slip joints of the iron work and the want of other secure longitudinal fastenings; but on the contrary it is well designed to resist compression. The flooring must then be able at the tower to resist the sum of the compressions produced by the all unbalanced weights which can be at once concentrated at the extremities of the nineteen stays.

There is one considerable element of stiffness which has not been taken account of in this treatment of the stays, which serves very materially to diminish the maximum stresses to which they might otherwise be subjected. This is the intrinsic stiffness of the cable itself which is formed of seven equal subsidiary cables formed into a single cable, by placing six of them around the seventh central cable, and enclosing the whole by a substantial wrapping of wire, so that the entire cable having a diameter of 12⅛ inches, affords a resistance to bending of from one sixth to one half, that of hollow cylinders of the same diameter and equal cross section of metal. Which of these fractions to adopt depends somewhat on the tightness and stiffness of the wrapping.

It is this intrinsic stiffness of the cable which is largely depended upon in the central part of the bridge, between the two longest stays, to resist the distortion caused by unbalanced weights.

As might be foreseen the distortions are actually much greater in the central part of the bridge than elsewhere, though they would have been by far the greater in those parts of the bridge where the stays are, had the stays not been used.

The center of a cable is comparatively stable while it is undergoing quite considerable oscillations, as may be readily seen by a simple experiment with a rope or chain.

Let us now determine the relative amount of the stresses in the stiffening truss, on the supposition that the actual stresses are some unknown fraction of the stresses which would be induced, if there were no stays, and the truss was the only means of stiffening the cable. We, therefore, have to determine only the total stresses, supposing there are no stays, and then divide each stress obtained by n (at present unknown) to obtain the results required. Let us draw the equilibrium polygon d which is due to a uniform load of depth xy, and which has a deflection bd six times the central deflection of the cable. The loading of the cable is so nearly uniform, that each of the ordinates of the type bd, may be considered with sufficient accuracy to be six times the corresponding ordinate of the cable. Any multiple other than six might have been used with the same facility. In order to cause the polygon to have the required deflection with any assumed pole distance it is necessary to assume the scale of weights in a particular manner, which may be determined easily in several ways. Let us find it thus :

Let W=one of the concentrated weights.
Let D=central deflection of cable.
Let S=span of the bridge
Let M=central bending moment due to the applied weights.

Then, if the pole distance$=\frac{1}{3}S$, $M=\frac{1}{3}S \times 6D=2SD$, for the moment is the product of the pole distance by the ordinate of the equilibrium polygon. Again, computing the central moment from the applied forces,

$$M=\tfrac{11}{2}W\times\tfrac{1}{2}S-5W\times\tfrac{1}{4}S=\tfrac{3}{2}WS,$$

in which the first term of the right hand member is moment of the resistance of the piers, and the second term is the moment of the concentrated weights applied at their center of gravity.

$$\therefore\ \tfrac{3}{2}WS=2SD\ \therefore\ W=\tfrac{4}{3}D,$$

Hence, if one-third of the span is to represent the pole distance or true horizontal tension of an equilibrium curve having six times the deflection of the cable, each concentrated weight when the span is divided into twelve equal parts, is represented by a length equal to $\frac{4}{3}$ of the deflection of the cable. The true horizontal tension of the cable will be six times that of the equilibrium polygon, or it will be represented, in the scale used, by a line twice the length of the span. Now taking b as the pole, at distances $bb_4=bb_4'=\frac{1}{3}S$, lay off $b_4'w_1=b_4w_1'=\frac{1}{2}W=\frac{2}{3}D$, so that they together represent the weight concentrated at b; and let $w_1w_2=W$, represent the weight concentrated at b_2, etc. Then can the equilibrium polygon d be constructed by making $dd_1 \parallel bw_1$, $d_1d_2 \parallel bw_2$, etc. If $bd=6D$ the polygon must pass through b_6 and b_6', which tests the accuracy of the work.

Now to investigate the effect of an unbalanced load covering one-half the span, let us take one half the load on the right half of the span and place it upon its left, so that xz and xb represent the relative intensity of the loading upon the left and right half of the span respectively, the total load being the same as before. If it is desirable to consider that the total load has been increased by the unbalanced load we have simply to change the scale so that the same length of load line as before, (viz, $b_4'w_5+b_4w_5'$) shall represent the total loading. This will give a new value to the horizontal tension also.

Now let a new equilibrium polygon c be drawn, which is due to the new distribution of the concentrated weights. It is necessary to have the closing line of this polygon c horizontal, and this may accomplish either, by drawing the polygon in any position and laying off the ordinates of the type bc equal to those in the polygon so drawn, or better as is done in this Figure by laying off in each weight line that part of the total load which is borne by each pier, which is readily computed, as follows: The distance of the center of gravity of the loading divides the span in the ratio of 17 to 27. Hence $\frac{27}{44}$ and $\frac{17}{44}$ of the total load are the resistances of the piers, or since the total load$=11W$, we have $b_4'u_6=\frac{27}{4}W$ and $b_4u_6'=\frac{17}{4}W$. Now make $u_6u_5=$the weight concentrated at b_5, etc., and $b_4'u_2+b_4u_1=$ that at b_1. Then draw the polygon c.

The polygon c has the same central deflection as the polygon d; for compute as before,

$$\therefore\ M=\tfrac{17}{4}W\times\tfrac{1}{2}S-\tfrac{5}{2}W\times\tfrac{1}{4}S=\tfrac{3}{2}WS$$

in which the first term of the second member is the moment of the resistance of the right pier, and the second term is the moment of the concentrated weights applied at their center of gravity.

By similar computations we may prove the following equalities;

$$d_5e_5=d_1e_1=-d_1'e_1'=-d_5'e_5';$$
$$d_4e_4=d_2e_2=-d_2'e_2'=-d_4'e_4';$$
$$d_3e_3=d_3'e_3'.$$

The quantities of the type de are proportional to the bending moments which the stiffening truss must sustain if it preserves the cable in its original shape, when acted on by an unbalanced load of depth bx, on the supposition that the truss has hinge joints at its ends, and is by them fastened to the piers. For in that case the cable is in the condition of an arch with hinge joints at its ends. The condition which then holds is this:

$$\Sigma(M_dy)=\Sigma(M_cy)$$

or,

$$\Sigma(M_d-M_c)\,y=0\ \therefore\ \Sigma(cd)\,y=0.$$

This last is fulfilled as is seen by the above equations, for to every product such as $+b_1d_1\times d_1c_1$ corresponds another $-b_1'd_1'\times d_1'c_1'$ of the same magnitude but opposite sign.

The polygon c could have been obtained by a second equilibrium polygon in a manner precisely like that used before, but as it appears useful to show the connection between the methods of treating the arch rib which is itself stiff, and the flexible arch or cable, which is stiffened by a separate truss, we have departed from our previously employed method for determining the polygon c, as it is easy to do when both c and d are parabolic.

Now let us compute the bending moment

$$=d_5 e_5 \times \tfrac{1}{3} S = M_c - M_d$$

$$M_c = \tfrac{27}{4} W \times \tfrac{1}{12} S = \tfrac{9}{16} WS$$

$$M_d = \tfrac{11}{2} N \times \tfrac{1}{12} S = \tfrac{11}{24} WS$$

$$\therefore \quad M_c - M_d = \tfrac{5}{48} WS.$$

Compute also the bending moment at the vertical through b_4,

$$M_c = \tfrac{27}{4} W \times \tfrac{1}{6} S - \tfrac{3}{2} W \times \tfrac{1}{12} S = WS$$

$$M_d = \tfrac{11}{2} W \times \tfrac{1}{6} S - W \times \tfrac{1}{12} S = \tfrac{5}{6} WS$$

$$\therefore M_c - M_d = \tfrac{1}{6} WS$$

Similar computations may be made for the remaining points, and this noteworthy result will be found true, that the bending moments induced in the stiffening truss by the assumed loading, are the same as would have been induced by a positive loading on the left of a depth yz, and a negative loading on the right of an equal depth yb. For compute the moments due to such loading at the points b_5 and b_4.

The resistance of the pier due to such loading $= \tfrac{5}{4} W$

$$\therefore M_5 = \tfrac{5}{4} W \times \tfrac{1}{12} S = \tfrac{5}{48} WS$$

and

$$M_4 = \tfrac{5}{4} W \times \tfrac{1}{6} S - \tfrac{1}{2} W \times \tfrac{1}{12} S = \tfrac{1}{6} WS, \text{ etc.}$$

We arrive then at this conception of the stresses to which the stiffening truss is subjected, viz:—the truss is loaded with the applied weights acting downward, and is drawn upward by a uniformly distributed negative loading, whose total amount is equal to the positive loading, so that the load actually applied at any point may be considered to be the algebraic sum of the two loads of different signs which are there applied. This conception might have been derived at once from a consideration of the fact that the cable can sustain only a uniform load, if it is to retain its shape; but it appears useful in several regards to show the numerical agreement of this statement with Prop. IV of which in fact it is a particular case. It is unnecessary to make a general proof of this agreement, but instead we will now state a proposition respecting stiffening trusses, the truth of which is sufficiently evident from considerations previously adduced.

Prop. VI. The stresses induced in the stiffening truss of a flexible cable or arch, by any loading, is the same as that which would be induced in it by the application to it of a combined positive and negative loading distributed in the following manner, viz: the positive loading is the actual loading, and the negative loading is equal numerically to the positive loading, but is so distributed as to cause no bending moments in the cable or arch, *i.e.*, the cable or arch is the equilibrium polygon for this negative loading.

By flexible cable or arch is meant one which has hinge joints at the points where it supports the stiffening truss. It need not actually have hinge joints at these points: the condition is sufficiently fulfilled if it is considerably more flexible than the truss which it supports.

The truth of Prop. VI has been recognized by previous writers upon this subject in the particular case of the parabolic suspension cable, and Rankine has erroneously applied it to the determination of the bending moments in the arch rib. It is inaccurate for this purpose in two particulars, inasmuch as in the first place the arch to which it is applied is not parabolic, though the negative loading due to it is assumed to be uniform, and in the second place the horizontal thrust is not the same for the different kinds of arch rib, while this assumes the same thrust for all, viz: that arising from a flexible arch or one with three or more joints.

A similar proposition has been introduced into a recent publication on this subject*, but in that work the truss stiffens a simple parabolic cable, and the truss is not supposed to be fastened to the piers, so that it may rise from either pier whenever its resistance becomes negative. As this should not be permitted in a practical construction the case will not be discussed. In accordance

* Graphical Statics, A. J. Du Bois, p. 329, published by John Wiley & Son, New York.

with Prop. VI let us determine anew the bending moments due to an unbalanced load on the left of an intensity denoted by bz. As before seen this produces the same effect as a positive loading of an intensity $yz=fm=\frac{1}{2}bz$ on the left, and a negative loading of an intensity $yb=fn=\frac{1}{2}bz$. Now using g as a pole with a pole distance of gf_2=one third of the span lay off the concentrated weight p_1p_2=that applied at b_1, etc., on the same scale as the weights were laid off in the previous construction, and in such a position that g is opposite the middle of the total load, which will cause the closing line to be horizontal. Then draw the equilibrium polygon a due to these weights. The ordinates of the type af are by Prop. VI proportional to the bending moments induced in the stiffening truss by the unbalanced load when the truss is simply fastened to the piers at the ends, and, as we have seen, each of the quantities af is identical with the corresponding quantity cd.

If the stiffening truss is fixed horizontally at its ends a closing line hh' must be drawn in such a position that $\Sigma(M)=0$, and as it is evident that it must divide the equilibrium polygon symmetrically it passes through f its central point.

As stated in a previous article, the maximum bending moments at certain points of the span are caused when the unbalanced load covers somewhat more than half of the span. In the case of a parabolic cable or arch the maximum maximorum bending moment is caused when this load extends over two-thirds of the span, as is proved by Rankine in his Applied Mechanics by an analytic process. Let the load extend then over all except the right hand third of the span with an intensity represented by $bz=q_3q_4'$. Then if $f_2'q_3=\frac{1}{2}f_2'q_4'$, the truss may by Prop. VI be considered to sustain a positive load of the intensity $f_2'q_3$ on the left of b_2', and a negative load of the intensity $f_2'q_4'$ on the right of b_2'. Using g' as the pole and the same pole distance as before, lay off the weight q_6q_5 concentrated at b_5, etc., so that g' is opposite the middle of the weight line. We thus obtain the equilibrium polygon e, in which the ordinates of the type ef are proportional to the bending moments of the truss under the assumed loading, when its ends are simply fastened to the piers.

Now bd was the ordinate of an equilibrium polygon having the same horizontal tension, and under a load of the same intensity covering the entire span. It will be found that $bd=\frac{27}{4}f_2e_2$, which may be stated thus:—the greatest bending moment induced in the stiffening truss, by an unbalanced load of uniform intensity is four twenty-sevenths of that produced in a simple truss under a load of the same intensity covering the entire span. This result was obtained by Rankine analytically. If the truss is fixed horizontally at its ends, we must draw a closing line kk', which fulfills the conditions before used for the straight girder fixed at the ends, as discussed previously in connection with the St. Louis Arch. By the construction of a second equilibrium polygon, as there given, we find the position of kk'; then the ordinates ke will be proportional to the bending moments of the stiffening truss.

The shearing stress in the truss is obtained from the loading, which causes the bending moment in the same manner as that in any simple truss. The horizontal tension in the cable, is the same whenever the total load on the span is the same, and is not changed by any alteration in the distribution of the loading, which fact is evident from Prop. VI. The maximum tension of the cable is found when the live load extends over the entire span, and is to be obtained from a force polygon which gives for its equilibrium polygon the curve of the cable itself, as would be done by using the weights w_1w_2, etc., and a pole distance of six times bb_4=twice the span.

The temperature strains of a stiffening truss of a suspension bridge are more severe than those of the truss stiffening an arch, because the total elongation of the cable in the side spans as well in the main span, is transmitted to the main span and produces a deflection at its center. This is one reason why stays furnish a method of bracing, particularly applicable to suspension bridges. But supposing that the truss bears part of the bending moment due to the elongation of the cable, it is evident that when the truss is simply fastened to the piers, the bending moments so induced are proportional to the ordinates of the type *bd*, for by the elongation of the cable, it transfers part of its uniformly distributed weight to the truss.

That load which the cable still sustains, is uniformly distributed, if the cable still remains parabolic, therefore that transferred to the truss is uniformly distributed.

When the truss is fixed horizontally at the piers, the closing line of the curve *d* must be changed so that $\Sigma(M)=0$, and the bending moments induced by variations of temperature, will be proportional to the ordinates between the curve *d* and this new closing line.

It remains only to discuss the stability of the towers and anchorage abutments. The horizontal force tending to overturn the piers comes from a few stays only, as was previously stated, and is of such small amount that it need not be considered.

The weight of the abutment in the case before us is almost exactly the same as the ultimate strength of the cable. Suppose that $st=sv$ are the lines representing these quantities in their position relatively to the abutment. Since their resultant *sv* intersects the base beyond the face of the abutment, the abutment would tip over before the cable could be torn asunder. And since the angle *vsr* is greater than the angle of friction between the abutment and the ground it stands on, the abutment if standing on the surface of the ground, would slide before the cable could be torn asunder.

The smallest value which the factor of safety for the cable assumes under a maximum loading is computed to be six. Take $st'=\frac{1}{6}st$ as the greatest tension ever induced in the cable, then *sr'* the resultant of *sv* and *st'* cuts the base so far within the face that it is apparent that the abutment has sufficient stability against overturning, and the angle *vsr'* is so much smaller than the least value of the angle of friction between the abutment and the earth under it, that the abutment would not be near the point of sliding even if it stood on the surface of the ground. It should be noticed that all the suspenders in the side span assist in reducing the tension of the cable as we approach the abutment, and conduce by so much to its stability. Also the thrust of the roadway may assist the stability of the abutment, both with respect to overturning and sliding.

STREET TRAMWAYS.

By Captain DOUGLAS GALTON, C.B., R.E., D.C.L., F.R.S.

From "Journal of the Society of Arts."

I cannot better commence this paper than by calling attention to the remarks made last autumn by Mr. E. Chadwick at Glasgow, in which he points out that the best remedy for the insanitary condition of towns by overcrowding is to cheapen transit by every means, so as to spread the population to fresh suburban lands, where ground rents are less expensive and sites more open.

Science has now rendered this comparatively easy by providing mechanical appliances that will, to a great extent, supersede the use of horse-power in public vehicles. The social problem in this matter is at least as important as the engineering problem, but it is only by public discussion that these appliances can be brought into more extended use.

The railway affords communication between *foci* of population—but the railway is especially calculated for conveying large numbers of passengers, and large quantities of goods in each train; and for the efficient working of the railway the distance between the points where the traffic is collected must be sufficient to allow of the train acquiring speed between its several stoppages; for unless this is the case one of the main advantages of a railway, viz., speed, is lost.

In towns, the points at which passengers desire to be taken up or set down are so numerous that the number of stations cannot be multiplied sufficiently to accommodate everybody. In the country districts, on the other hand, the traffic is scattered, and the railway itself has to be fed by roads, along which the traffic comes to the station in quantities which would be insufficient to fill a complete train. The ordinary railway is inapplicable to either of these cases; but cheapness of transport is as desirable in the collection of traffic as it is in its subsequent conveyance. The cost of transport depends on the smoothness of the road.

Thus the tractive force required to draw one ton on a level on well laid iron rails on a railway is about 7 lbs.; stone tramway (smooth), 20 lbs.; asphalte, 27 lbs.; wood pavement, 38 lbs.; macadam (very good), 40 lbs.; ditto, gravelly, 50 lbs.; ditto, new, 96 lbs.; soft, sandy, and gravelly ground, 210 lbs. Thus after the iron rail the smooth granite affords the best surface. The provision of a smooth surface for wheel tracks for ordinary horse traffic is of old standing. A description of this system, as adopted in Italian towns, was given by Mr. P. Le Neve Foster, jun., C. E., in a former number of the Society's *Journal*. It may be seen in the Commercial Road. Mr. Chadwick has proposed, in lieu of the granite slabs, asphalte wheel tracks. These wheel tracks must necessarily be somewhat broad, to enable them to accomodate the various widths of vehicles. Where one horse is used the intermediate space may be so paved as to afford a foot-hold for the horses; but where two horses abreast are used a proportion of their useful power is lost by the slippery foot-hold afforded by the broad slabs.

The harder the material of which the wheel track is made, the more slippery does it become. It follows that, for the convenience of horse traffic, it is preferaable to limit as much as possible the width of the wheel track; but when this width is closely limited it becomes necessary to provide it with a flange, or some means of keeping the wheels in their place.

The tramway, as is now understood, consists of an iron rail adapted to a particular width between the wheels, and constructed so as to admit only of a special form of wheel.

It is to this form of tramway that recent legislation has applied, and it is to its aspect as a means of extending the advantages of the railway system that I propose to devote this paper.

TRAMWAY LEGISLATION.

Parliament first recognized the importance of tramways by general legislation in 1870.

The General Act of 1870, to facilitate the construction and to regulate the working of tramways, enables the Board of Trade to make provisional orders authorizing the construction of tramways, such tramways to be constructed, either by the local authority or authorities of the district, out of rates, or out of money borrowed on the security of rates; or else by private companies, with the consent of the local authority, or of the road authority of the district. But in cases where the proposed tramway lies in more than one district, the Board of Trade may overrule the opposition of a minority of districts, provided two-thirds of the proposed length lies in districts in which the authorities are consenting parties.

The permission to use steam power is limited to the time during which the restrictions imposed by the by-laws are adhered to; and power is reserved to the Board of Trade to vary the by-laws.

The steam engine is to be so constructed that, if it at any time attains a speed of more than ten miles an hour, the steam shall be at once shut off by self-acting machinery, which shall also apply the breaks. The engine shall be fitted with an indicator and recorder of the speed, with a fender to throw off obstructions, and with a bell to be rung as a warning when necessary, and from time to time, to give notice of the approach of the engine. The engine shall be free from noise produced by the blast and clatter of machinery; it shall not emit steam or smoke; no fire shall be visible from it; the machinery shall not be exposed to within four inches level of the rails; no hot air shall issue in a way to annoy passengers; the entry to and exit from the car shall be separate from the steam engine and its appurtenances.

The by-laws specially limit the actual rate of speed to be allowed, which may vary in each case, but they provide that the speed through moveable facing points shall not exceed four miles an hour. In the event of a horse being frightened when near any steam engine in motion on the tramway, the driver of the engine shall immediately bring the engine to a stand.

It is noteworthy that more progress would seem to have been made in foreign countries, in the use of steam as a motive power for tramways, than in this country. It is in use at Brussels and Vienna, and is on trial at Paris, Stockholm, and Copenhagen, Philadelphia, Chicago, San Francisco, and New York.

AVERAGE COST OF HORSE TRACTION ON TRAMWAYS.

In the discussion of the question of steam and horse power for tramways, it is necessary, first of all, to understand the actual merits of each, so far as cost of working is concerned; and if there is any pecuniary advantage in the use of steam, to consider how far it is counterbalanced by other difficulties.

The estimate given by Mr. Alphonse Spee, of the Société des Ingénieurs de l' Ecole de Liége, of the cost of horses to horse a tram-car capable of holding 44 persons, drawn by two horses, on the Bois de la Cambre tram-road at Brussels, having gradients of 1 in 33, and an incline nearly 1¼ miles long, of 1 in 100, are as follows :

COST OF WORKING THE TRAMWAY TO THE BOIS DE LA CAMBRE IN BRUSSELS BY HORSE POWER.

	£	s.	d.
Ten horses, at £37 10s.	375	0	0
Stables, at 10 square meters per horse=100 square meters, at 16s. 8d. per square meter, × £1 13s. 4d. per horse, to cover cost of building	250	0	0
Yards, 10 square meters per horse; 100 square meters, at £1	100	0	0
Total	725	0	0
Which, at 5 per cent. per annum, = say 2s. per day. Daily keep of each horse :			
Food	0	2	1
Harness, &c.	0	0	10
Total	0	2	11
Or say, £1 9s. 2d. for 10 horses.			
Sinking fund for horses, at 20 per. cent. on £375	75	0	00
Which is equivalent to (per day)	0	4	1½
Therefore 2s. × £1 9s. 2d. × 4s. 1½d. =per car per day	1	15	3½

The horses perform each total journey of nearly sixteen miles a-day. In Belgium, on tramways with gradients not exceeding 1 in 100, and with cars holding 30 passengers, drawn by one horse, the cost for horse cars was estimated at 17s. 6d. per day per omnibus.

The cost of running expenses in the best managed horse tramway lines in England, including horse hire, horse keep, drivers and pole-shifters' wages, but excluding stable rent, car repairs, and sinking fund, have been stated at 8d. per car-mile run.

The cost of horse power to the London Tramway Company has been published as follows :

		£	s.	d.
1 car-driver, at 25s. per week; 1 conductor, at 20s. "	45s.	117	0	0
12 horses required to work 1 car; cost of keep, wear, &c., of each horse inclusive of deaths and loss by re-sale, 22s. per week; 26,260 miles per annum; 12 horses at 22s. per week		686	8	0
Repair of car, at ¼d. a mile		27	7	1
Total		830	15	1
Or per car per day		2	0	0

This does not include interest of money, or the cost of lighting, cleaning, and general expenses, which would be approximately the same in horse and steam cars, and may therefore be omitted for purposes of comparison.

The cost of the horse traffic in the Wantage tramway is stated to have been as follows, per day of twelve hours :

	£	s.	d.
Four horses, at 3s.	0	12	0
Two drivers	0	6	0
Conductor	0	2	4
Oil and light	0	0	2
Wear and tear estimated	0	6	0
Rent of stables	0	1	0
Total	1	7	6
Cost of working per mile	0	0	8½

A great difficulty in the traction of tram-cars results from the frequent starting and stopping of the car for taking up and setting down passengers, because of the heavy strain at starting.

The following table of some experiments, published by Mr. Alph. Spee, shows the tractive force required to start a tram-car on various sorts of roads, the weight of the car, with its load, being about four tons :

Nature of Road.	On Level.	On incline. 1-200th.	1-100th.	1-50th.	1-20th.
	lbs.	lbs.	lbs.	lbs.	lbs.
Paved road........	264.5	308.5	352.6	440.8	705.3
Railway.........	44.	88.1	132.2	220.4	484.8
Tramway: Straight, clean..	88.1	132.2	176.3	264.5	529.
Tramway: Straight, dirty..	176.3	220.4	264.5	352.6	617.
Tramway: Curved, clean...	176.3	220.4	264.5	352.6	617.
Tramway: Curved, dirty...	264.5	308.5	352.6	440.8	705.3

A comparison between this table and the previous one would seem to show that the tractive force required to start a car is from four to five times as great as that required to keep a car in motion. Therefore, the ordinary tram-car, whilst in motion, runs smoothly so far as the horses are concerned, but when it is stopped, and has again to be started, the strain is enormous on the horses, and wears them out rapidly. In America, several persons have invented appliances, termed "car starters," to relieve the horses of this strain at starting, by accumulating the force lost in stopping by means of springs compressed by the action of stopping, and then releasing the springs at the moment of starting, so as to use this accumulated force in moving forward the car, and thus relieve the horses. None of them seem to have attained any extended application in practice.

MECHANICAL APPLIANCES FOR TRACTION ON TRAMWAYS.

The use of mechanical appliances to relieve the horses on road carriages is of old date, but it would lead me beyond the limits of this paper to describe the progress of invention in this respect.

The earlier carriages moved by power other than animal power were devised for running upon ordinary roads. Of these, the most successful were the inventions of Mr. W. Hancock, some of which ran regularly between Paddington and the City before the year 1837. The enormous proportion of tractive force to the weight of the vehicle required for moving carriages on ordinary roads, and especially on macadamized roads, offered great impediments to inventions of this class.

The introduction of iron tram rails on to the ordinary road has afforded a new starting point.

Every variety of motive power has been sought to be applied to the movement of tram cars. Steam, superheated water, water under high pressure, hot air, ammoniacal gas, carbonic acid gas, compressed air, steel springs, haulage by ropes, and electricity as a motive force.

The latter has not yet hitherto yielded any successful result.

The use of ropes for haulage is only applicable in limited cases. At San Francisco, Mr. Holliday constructed a rope tramway, about three-quarters of a mile in length, on an incline of 1 in 10. The rope was enclosed in an iron pipe, below the surface of the road, with a groove to admit a flat bar, which was fixed to the car. The end of the flat bar was provided with a clamp, which could be attached to or detached from the rope at the will of the conductor. But the opening in the pipe was liable to fill with dirt.

All the other methods of propulsion—except steam generated by the combustion of fuel in the car, or hot air or gases expanded by heat generated in the car—are limited by their own nature. The force which they exert is stored with more or less economy, for a defined object; if, from unexpected causes, a greater amount of force than usual is required, there is no margin left, and failure is the result. If the stored up force is suitable at one time it is insufficient at another. For instance, on a tramway with numerous alterations of gradients, the stored up force must be sufficient for the steepest gradient. Such appliances are, therefore, limited in their application in respect of time, in respect of weight, and in respect of gradients.

But the weight of these appliances, whether springs or air compressed in cylinders, or other appliances, increases very rapidly with the stored up strength, and thus adds largely to the whole weight to be moved.

With steam, on the other hand, such temporary alterations in the amount of work to be done are easily overcome by increasing the pressure of steam, by means of an additional consumption of fuel.

MOTIVE POWER BY MEANS OF STEEL SPRINGS.

Force obtained by springs does not appear to afford great promise at present.

The work necessary to bend a bar of steel to rupture may be expressed by the formula :

$$\frac{1}{6} \times \frac{B^2}{e} \times \frac{El}{Z}$$

Where

B = maximum tension per inch to which the bar is subjected.

e = the modulus of elasticity.

E = the moment of inertia of the bar assumed rectangular.

L = total length of bar, and

Z = distance from the central line of the bar to the line of maximum extension.

The average of the tractive force required on the journey being assumed at from 40 to 45 lbs. per ton on a level tramway, including the resistance at starting, it will be found that with a car weighing from 4 to 4½ tons with its load, a weight of springs, made of the best steel now in use, nearly equal to that of the car will be required to effect a journey of half a mile.

For the present, therefore, it is not probable that this mode of obtaining force can be utilized for locomotion.

MOTIVE POWER BY MEANS OF SUPERHEATED WATER.

The use of superheated water as a motive power has been adopted in Chicago, New Orleans, and New York, by M. Lamm. A certain quantity of water heated to a very high temperature stored in a reservoir at the beginning of the journey, gives out the steam necessary during the usual journey of the omnibus. The reservoirs can be applied to the carriage itself, or to a separate vehicle.

To avoid priming, the reservoirs are only three parts full, the initial temperature being about 374° Fahr., which is equivalent to a pressure of 12 atmospheres. Supposing that this temperature is lowered, by the end of the journey, to 270°, it will be seen that the quantity of water turned into vapor is 12 per cent. of the whole.

Experiments at Seraing, in 1874, showed that about 60 per cent. of the theoretical power could be utilized; but, of course, this is exclusive of loss of heat by radiation, which must be prevented as much as possible by non-conducting coverings, as well as the loss by escape of steam, and especially by priming, that is to say, the escape of water with the steam.

It has been estimated that cars, with two tons of water, would make a journey of about five miles on the level, or about two and a half miles on an incline of 1 in 50. The difficulty appears to lie in starting towards the end of the journey, in which case some special car-starting apparatus becomes necessary. Moreover, the discharged steam is very moist, and great difficulties exist in so condensing it as to prevent its being seen.

Mr. Todd and Mr. Bede have also proposed other forms of this class of car. The former placed his cylinders so as to be surrounded by the heated water. Mr. Bede's car has been in use at Brussels. Four horizontal reservoirs are placed under the seats, united to vertical reservoirs, on each side of the central part of the car. The steam is taken from the upper part of the vertical reservoirs, and passed through the roof. The cylinders are 4½ in. diameter, by 14 in. stroke. The driving-wheels are 2 ft. 3 in. diameter. The reservoirs contain about 300 gallons of water heated to 365° Fahr., and at a pressure of 10 atmospheres. This reserve of heat suffices for a journey of 50 minutes, at the usual speed of tram-cars; the cars carry a load of about 1½ tons ; the cars can easily pass curves of 36 feet radius, and will ascend an incline of 1 in 30 with an effective pressure of 4½ atmospheres. The adhesion of this car in starting on inclines is, however, too small, and entails trouble.

MOTIVE POWER BY MEANS OF COMPRESSED AIR.

Cars moved by compressed air have obtained a certain development.

Mr. Scott-Moncrieff has devised a car which has been in use on the Vale of Clyde tramways between Paisley Road and Govan, which performed a journey of 1½ miles each way for each charge of air; thus obtaining a distance of 3 miles without refilling.

The chief difficulty which inventors have had to contend with in working with compressed air is the excessive cold produced in the exhaust.

Moreover, in any mechanical arrangement, such as a locomotive carrying a definite quantity of compressed air, and absent from time to time from the original sources of supply at the pumping stations, it is absolutely necessary that the fullest advantage should be taken of the limited power stored in the receivers. The only way in which this can be done is by using the air expansively, and as the pressure is always decreasing towards the end of the journey, this expansion must vary correspondingly.

The peculiarity of the Scott-Moncrieff system is the valve gear, which allows the compressed air to issue from the reservoir at a uniform pressure, which may be varied at the will of the driver. By the arrangement adopted, the air is always exhausted at the atmospheric pressure, the effect of which is not merely to obviate the difficulties arising from excessive cold, but also to propel the car in silence, and utilize to the utmost the available power. The storage of the air and the requisite machinery are, moreover, brought within the dimensions of an ordinary street car.

In general appearance the Scott-Moncrieff car is in every way like an ordinary street car, with this exception, that there is an entrance direct from each end by convenient steps, instead of from the small space at the sides of the car, between the splashboard and the ends of the carriage framing, as is the case in other forms of tram cars. The tanks containing the compressed air are attached to a framing below the floor of the car, and are placed in sets of three at each end, leaving room for a smaller and stronger framing at the center, where are placed the engines, valve gear, driving wheels, breaks, &c. These appliances do not interfere with the accommodation of the interior of the car. At each end of the car there is a platform, the front one being occupied by the driver, and the other being free for the conductor, and for the entrance and exit of passengers. At convenient places pressure guages are placed, indicating the pressure of air in the tanks and in the valve casing, as well as tell-tales to show the position of the expansion valves. Starting handles and breaks are provided at each end, so that the car may run in either direction. The new car can be stopped and started readily, and propelled at variations of speed, and when the engines are at work there is no noise.

The expenses of running these cars per mile are stated by the inventor to be as follows:

	Pence per car mile.
Fuel at 10s. per ton	0.5
Drivers at 30s. each, allowing for relays at the rate of three drivers to every two cars	1.35
Enginemen and firemen at 4s. a day each	0.125
Depreciation of fixed machinery, ten per cent	0.125
Depreciation of cars, ten per cent	0.625
	2.725
Contingencies, ten per cent	0.272
	2.997

The advantages claimed by the inventor for this machine are the absence of danger from explosion, and the economy in fuel for compressing the air, which he estimates at 3 lbs. per horse-power.

Another form of car moved by compressed air was proposed by Mr. Mekarski, and constructed by M.M. Delletrez at Paris. In this machine the pressure at which compressed air is allowed to issue can be regulated at will, and hot water is applied to keep up the temperature of the exhausted air. A special cylinder is brought into play to assist in starting, and the force acquired in descending inclines is used to store up air, and thus provides additional motive power.

The following formula expresses the total work due to compressed air:

$$PV + PVK \log. \frac{P}{P^1}$$

When

V = volume of compressed air.

P = pressure in lbs. per square inch at the beginning of the journey.

P^1 = pressure in ditto at end of journey.

K = a constant.

From the formula it will appear that the disposable force from compressed air is about one-third of that from an equal volume of hot water. Moreover, compressed air requires more expensive fixed apparatus than that required with hot water.

There is another form in which stored-up heat has been proposed. Mr. Lamm placed a cylindrical receiver on the roof of the car filled with hot water; in this he placed another cylinder, containing liquid ammoniacal gas, obtained from sal ammoniac, heated in connection with hydrate of lime.

The gas became disengaged under the influence of the hot water by which it was surrounded, and was passed into working cylinders, whence it was carried after use into the hot water reservoir, where it became absorbed, giving its heat to the water, whence the temperature of the water was increased instead of diminished during the journey.

Carbonic acid gas is also a gas which would appear at first to provide an advantageous method of obtaining motive power. At the freezing point it is liquid under a pressure of 40 atmospheres, and at 176° Fahr., it has in its gaseous state a pressure of 80 atmospheres. But independently of its high price, the difficulty of regulating the enormous force generated by it has hitherto prevented its application.

Hot air engines are too clumsy and noisy for use on tramways. There remains, therefore, only steam carriages to be considered.

STEAM TRACTION.

The steam carriages and engines with their own fire and boiler may be classed under two heads:

1st. Those in which the motive power is contained in the car itself which conveys the passengers.

2nd. Those in which the motive power is separate from the car carrying passengers, that is to say, detached engines, such as is the custom on railroads.

1. Under the first head there have been numerous inventions. Messrs. Grice and Long, of Philadelphia, Mr. G. Francis Train, Mr. Nairn, were among the earliest, but these inventions more nearly resembled the ordinary locomotives, in that they allowed the escape of smoke and steam, and were not free from noise. Mr. Todd, in 1871, produced a machine intended to obviate these inconveniences. Mr. Remington, in 1872, tried a steam car in New York, on a tramway with curves, having a radius of 50 feet, and inclines of 1 in 14. There are many others.

The Grantham steam car, however, of those cars which carry their own motive power, seems to be the most successful of those which have been tried in this country.

The original car is 27 ft. 3 in. in length, 11 ft. 1 in. high, and 6 ft. 6 in. wide; is divided into first and second class passenger compartments entered from the end platforms, with the boiler and machinery fixed in the center. It runs on four wheels, one pair for driving, the other pair fixed to a radial axle for easing the curves. It is propelled backwards and forwards without turning at either end of the line, and only requires to be replenished with water at stated intervals. It is driven from either end by removable levers, the driver having complete control of the machine, as regards turning on, shutting off, or reversing steam, as well as applying the break-power, which is sufficient to enable the car to be brought to an almost immediate standstill. It is constructed to carry, both inside and outside, sixty passengers.

In the centre is the steam boiler and condensing apparatus; the cylinders, which are placed underneath, are 6 in. diameter, and the length of stroke, 10 in. The exhaust is led into a copper vessel fixed in the uptake of the boiler; this allows the steam to expand, and pass away from the chimney-top superheated. In an improved car the bogie system has been adopted at the end furthest from the driving-wheels, to give steadiness, by means of a long wheel-base. By this means the rigid wheel-base is reduced to 3 ft.. and, therefore, the car can travel easily round curves. Moreover, an arrangement connected with the bogie frame enables the car to be guided, so that no moveable switches are required at the sidings. By this arrangement, also, the car can be guided off the rails at will, and on to them again when off. The levers for working the engines, and managing the car and breaks, are connected with each platform, so that the conductor stands always at the end which is in front. This car, in its working, is free from noise, in consequence of the arrangement for condensing the steam.

2. The second method in which steam is applied to tram-cars is by means of a separate engine, that is to say, substituting a small engine for the horses used in horse-cars. This system is that now adopted by Messrs. Merryweather. Their engine is somewhat less than half the length of an ordinary tram-car, which it resembles in appearance; and therefore, in contrasting the steam-power with horse-power, it occupies less space than the horses of a tram-car would occupy. At each terminus it is disconnected and brought to the front of the car. This operation does not occupy more (if so much) time than is required with horses. The boiler is multitubular, so that dangerous explosions cannot occur. Each engine weighs about three tons, with sufficient water and fuel to run for four hours. The consumption of fuel is about 20 lbs. weight per hour. The pressure of steam is about 100 lbs. The engines are noiseless, and emit neither smoke nor steam. The exhaust steam is disposed of by a condensing apparatus. In this apparatus the steam is passed through a series of nozzles, arranged so as to include a large mixture of hot air with the steam, by which means part is thus condensed; and of the remainder, a further portion is condensed by passing it through wire gauze or bundles of wire, and through a surface condenser, and the residue is turned either into the smoke-box or through the fire. This plan avoids the necessity of carrying a large quantity of water; thus the whole weight of the engine is kept to a minimum, thereby reducing very considerably the working expenses, and the wear and tear on the permanent way. The engines have all four wheels coupled; they can ascend heavy inclines, and, from their short, rigid wheel base, can pass round the sharpest curves, and they are sufficiently powerful to draw two or more loaded passenger cars. For very steep inclines they have a small auxiliary cylinder, which is fitted in the locomotive; this cylinder works a pitch chain, which is connected round a drum fixed on both axles of the car, by which arrangement the whole power of the engine is developed and extended to the car. They can be propelled at any required speed, at the will of the driver; the break power can be immediately applied, pulling up the car far quicker than can be done at present with the ordinary horse-cars. The engine is fitted with the necessary self-acting appliances for shutting off steam and applying breaks, if the driver should exceed the prescribed rate of speed. This is effected by means of a centrifugal governor driven from the locomotive wheels, and acting upon a valve in the steam pipe leading from the boiler to the engine. The starting and other levers, as well as the fire-hole door, are ready to the hand of the driver, who has an unobstructed view of the roadway on all sides, and, from the simplicity of the engines, a skilled mechanic is not required to drive them.

As a recent contribution to this class of steam-engines, may be mentioned the plan of Mr. Matthewson, in America, who, with the idea of not frightening horses, proposed a steam-engine in the shape of a horse to draw the car.

The machine consists of a platform with a canopy over it, supported on two wheels, which carries a wrought iron tank containing gas at pressure of from 60 lbs. to 100 lbs. per square inch, to be used as fuel for producing steam. In front of the platform is a tubular boiler and fire-box, and two cylinders enclosed in a metal case, which has all the external appearance of a horse; under the horse are two driving wheels of small diameter. The condensation of the steam is effected by means of water, contained in a receptacle on the roof of the passenger car.

The reason why horses are frightened at carriages which are moving towards them without apparent means of propulsion, would seem to be that they fancy the carriages are being backed upon them; but the horses would soon lose their fears from this cause, if the noise of the engine and the escape of steam are avoided.

COST OF STEAM TRACTION.

The cost of the steam tramways in Brussels, having a gradient of 1 in 33 and an incline of 1 in 100 for $1\frac{1}{4}$ miles, are stated by Mr. A. Spee to be as follows:

Outlay:

	£	s.	d.
1. Engine	600	0	0
2. Engine-house, at 36 square yards per engine, costing £2 8s. 4d. per square yard	72	0	0
3. Water supply and workshops	72	0	0
To which add 25 per cent. for reserve engines in the proportion of one in reserve to four in use	186	0	0
	930	0	0

	Cost per day. £	s.	d.
5 per cent. per annum upon £930	0	2	8
Daily expenses of running:			
440 lbs. of coke at £1 4s. 2d.	0	5	0
Oil, grease and various	0	2	1
Attendant	0	4	2
General repairs and Sinking Fund:			
At 10 per cent. on outlay for engines, including reserve engines	0	4	4
Total	0	18	3

This compares with £1 15s. $3\frac{1}{2}$d. before mentioned as the cost of horse traction.

The following is stated to be the cost of working the Grantham steam-cars:

	£	s.	d.
1 engine-driver, at 35s. per week; 1 stoker, " 25s. "; 1 conductor, " 20s. " — £208	208	0	0
Fuel—7 lbs. of coke per mile for 26,260 miles=82 tons, at 15s.	61	10	0
Oil, tallow, waste, and sundries taken at $\frac{1}{4}$d. per mile—26,260 miles	27	7	1
Water supply, at 1s. per day	18	5	0
Repairs of car and machinery—26,260 miles at 1d. per mile	109	8	4
	424	10	5
Or per car per day	1	3	3

Exclusive of interest of money and cost of lighting, cleaning, &c.

This would compare with the £2 per car per day before mentioned as the cost of working of the London Tramway Company.

RELATIVE ADVANTAGES OF THE COMBINED CAR AND ENGINE AND THE DETACHED ENGINE.

There is probably no very practical difference in the actual cost of running the steam tram-car with its engine contained within itself, and the cost of the tram-car drawn by a detached engine. The question as to which is preferable must therefore depend on other considerations.

The tram-car with its steam engine forming a part of itself, is very convenient and compact, especially in towns, and it will probably be preferred where a succession of single cars are required to run consecutively at short intervals, and solely for the accommodation of passenger traffic. On the other hand, when companies already possess a stock of cars, the detached engine will enable them to utilize the cars they already possess. Also, where other conditions prevail, where an extra number of passengers require to be occasionally conveyed—or where the tramway can be utilized to convey goods and merchandize as well as passengers, it is probable that the detached engine would be more advantageous than the combined steam tram-car, and I understand that the Wantage Tramway Company have now one of Messrs. Merryweather's engines at work on their line.

ADVANTAGES OF STEAM TRACTION OVER HORSES OR OTHER MECHANICAL APPLIANCES.

This brief *resumé* of the various methods which have been proposed for the propulsion of tram-cars by mechanical appliances, shows very clearly that steam generated by a fire in the car is the only method which has as yet been successful; and that the other methods are, for the present at least, only toys, but, no doubt, very interesting toys.

The steam tram-car has attained a practical *status* or position. The saving of cost by steam traction over horse traction is also abundantly manifest. The cost of working by steam traction ought in no case to exceed two-thirds that of horse traction, and it will in most cases be not more than one-half.

The Grantham steam car and Messrs. Merryweather's steam cars and detached steam engines appear to comply with the Board of Trade requirements, viz., that the steam shall be disposed of after use, imperceptibly and without noise, and that the speed shall be regulated by self acting machinery. By the other regulations of the Board of Trade as to a warning bell, and as to stopping and speed, the general public appear to be adequately protected.

The essence of the tramway is that it should facilitate the movement of small quantities of traffic along existing thoroughfares, as contra-distinguished from the railway, which conveys a large bulk at a time along a road reserved to itself. Wherever the traffic requires long trains of passengers or goods, the tramway should give place to the railway. The tramway engine must, therefore, be essentially a light engine, but it must suffice occasionally for steeper inclines than are in general use on railways.

The limit of weight should be from $2\frac{1}{2}$ to 3 tons on each wheel, unless very much stronger roads than are now laid down, be adopted.

The cost of tramways in towns is considerable, owing to the expense of the pavement, which must be laid and maintained in good order between, and for 18 inches on each side of, the rails. In country districts the cost ought not to be heavy. The following, however, is stated to be the cost of the Wantage Tramway, $2\frac{1}{2}$ miles long, and laid for the greater parts of its length alongside of a very level high road. It has one bridge over a stream, built under the requirements of the Board of Trade, which, it is said, added to the cost. The cost of this line at last September was about as follows:

Purchase of freehold land	£1,800
Construction of line..........	4,600
Rolling stock..................	1,000
Legal, Parliamentary and miscellaneous expenses.........	2,600
	£10,000

The Grantham steam car is in use on the Wantage tramways; but in this car the cylinders are 4 in. in lieu of 6 in. as now made. The car in use on this line can carry 60 passengers—it weighs 8 tons with coke and water, and has carried in addition 5 tons of passengers. When empty it weighs 6 tons 10 cwt. The cost of the car was £800. The Wantage tramway is $2\frac{1}{2}$ miles long—it has gradients of 1 in 50 for 350 yards—the sharpest curve is 75 feet radius. The cost of working the Grantham steam car on the Wantage line per day of 12 hours, as nearly as can be ascertained, is given as follows:

	s.	d.
Distance traveled per day, 40 miles.		
Weight of gas coke, 240 lbs.		
Weight of steam coal, 56 lbs.		
——296 lbs. cost	2	$9\frac{1}{4}$
Fuel for lighting..............	0	$1\frac{1}{2}$
Oil and light for car...........	0	3
Driver's wages................	5	0
Stoker's wages.................	3	0
Conductor's wages............	2	4
Estimate wear and tear........	4	0
	17	6

Cost of working per mile, $5\frac{1}{2}$d. for steam car. This in contrast with the £1 7s. 6d. per day, and $8\frac{1}{4}$d. per car mile mentioned before, as the expense of horse traffic on the Wantage tramway.

The engineer says that he would prefer a 40 lbs. rail in lieu of the present 30 lbs. rail. It will, however, be observed, that the legal and Parliamentary expenses are excessive, notwithstanding the facilities afforded by the General Act and the provisional orders of the Board of Trade.

CONCLUSION.

The general conclusion to which the consideration of this subject brings us, is that the problem of the application of steam to tramways has been so far solved by the Grantham and Merryweather steam cars and engines, that steam traction may now be advantageously brought into operation on all tramways. The cost of steam traction would certainly not exceed two-thirds (probably not one-half) of that of horse-traction; and it would be more humane and convenient. Its adoption will therefore afford a large margin of profit to the existing tramway companies, who now work their lines with horse power. As a result of the application of steam traction to tramways, we may safely look to the extension of steam-worked tramways for supplying cheap and convenient locomotion to the small towns and large villages which do not now enjoy railway communication, whose traffic would scarcely repay the construction of the more complete and expensive railways. The question of constructing light railways has often been mooted, but without success in this country. We have laid down a certain standard of excellence for our railways, and however much engineers and directors have desired to extend the railway system, by means of light and cheap railways, the requirements of the Board of Trade have been such as to prohibit the construction of economical lines. The argument of the Board of Trade is, that if a railway is once open, although it may have been designed for light traffic, there is nothing to prevent heavy traffic passing over it. This argument is not one which it is necessary to discuss here, except to observe that its result is that we should look all the more to the development of tram-roads in all localities where there is not a sufficient amount of traffic to support a railway of the standard pattern.

In a new country, where no roads exist, and where the railway is the pioneer road, railways of cheap and light construction will continue to be adopted; but, in a fully settled country, possessing railways of the European standard, and already provided with roads, the tramway will be a fitting auxiliary to the railway, and a supplement to the ordinary road as a means of reducing the cost of conveyance.

The tramway can follow the line of the high road, with occasional deviations to avoid steep hills or very sharp turns. From its nature, the tramway requires a less expensive permanent way than the railway, for the expense of a permanent way depends on the weights passing over it and the speed at which these weights are moved. The limit of the greatest weight per wheel moved on a tramway will probably be that on the wheels of a railway wagon, for, in country districts it will occasionally be of great advantage to have the power of conveying a truck-load of goods to its destination without transhipment. The tramway traffic moves at low velocities; the limit of weight on railways, on the other hand, depends on the weight of the heaviest engines, and these move at high velocities. A tramway requires no expensive stations or platforms, as the passengers or merchandise can be taken up or set down at any point of the journey; no expensive signals are wanted; the only special requirement in the construction to which it is desirable to attend is, that the guage should be that of the railway system, viz., 4 ft. 8½ in., so that, when necessary, the railway truck may pass on to the tramway.

I trust I have been able to show you that the adoption of steam traction on tramways will prove eminently advantageous to street traffic in towns; that it will extend to the artisan population similar advantages to those which the railway has long extended to professional and business men, viz., that of being able to sleep in pure country air at a distance from their work; and that it will afford a long desired supplement to the railway system, by means of which those unfortunate towns and villages which have not held out sufficient promise of traffic to induce a railway company to approach them, may receive the advantages of cheap transport, whilst at the same time the adoption of steam traction affords a certainty of large profits to the tramway companies.

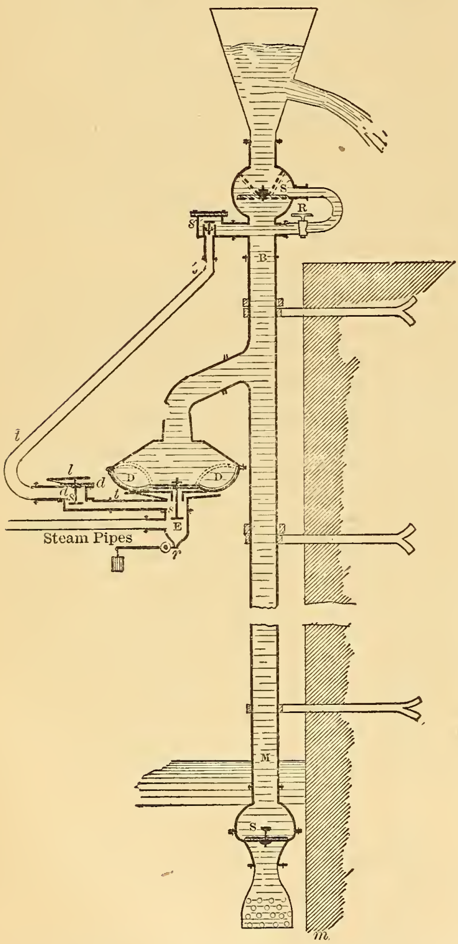
OSCILLATING WATER-COLUMN PUMP.

Translated from "Annales des Ponts et Chausées."

Let us conceive a vertical pipe full of water plunged into a drainage basin and furnished at each end with a valve opening upward. Suppose, further, that a certain quantity of steam be at first introduced into this tube, protected by a flexible rubber envelope to prevent condensation, then put in contact with cold water. Under these conditions, the vertical pipe with its accessories becomes a pump; a certain quantity of water being expelled by the upper valve at the moment when the steam is admitted, and an equal quantity being drawn by the lower valve when the steam is condensed.

The working of this pump has, for each discharge of water, two motions, in each of which a water column on the pendulum plan, first receives a certain amount of force which it afterwards returns. This last action may be utilized to produce expansion and assure by its action a continuance of its working.

Such a pump is represented in the cut on the scale of $\frac{1}{30}$. Several attachments are added to the main pipe and three small valves, employed for the distribution of steam, to the movable parts above named; that is to say, to the two valves and rubber envelope. The remainder of



the machine is composed of fixed parts, consequently not very liable to get out of repair.

The pump consists of a main-pipe BM plunged into a basin from which the water is to be raised and emptied into a tank or any reservoir. At the lower part of this pipe is a retaining valve S; at the upper part a valve S′ prevents the return of water. It may have, between the valve S′ and the tank, a delivery pipe of a certain length with or without a reserve of air. On one side of the pipe BM is another pipe of the same diameter leading to a space limited by two castings, between the collars of which is fixed the frame of a diaphragm DD made of canvas faced with rubber. To the central part of this diaphragm, intended to be applied to the sides of the upper and lower castings alternately, is a fixed plate formed of two metal discs. When the machine is not in motion or, at least, when the diaphragm does not raise the central plate, the latter, acting by its weight on the end of the rod of a small valve *s*, which a spiral spring keeps in place, forces this little valve to remain open. This valve regulates the admission of steam. This may be called the slide valve of the machine; it opens and closes suddenly. The steam, once admitted, penetrates the space between the castings through a number of holes made on a circumference having the same center as the lower casting and placed outside the circle covered by the central plate. The forms of the castings, the metalline plate, and the diaphragm are such that the flexible part of this last can, under the action of steam, be raised and take the position indicated by the dotted line as long as, by its proper weight, the central plate remains in place. The small valve *s*′, intended, at certain times, to stop the passage in the tube *ttt*, bears upon the top of its rod a small diaphragm *dd* to which is attached a check. When needed, a spring *l* made of a steel plate fixed to the check by two rivets, acts upon the extremity of the valve *s*′, concurring with the atmospheric pressure to resist the interior pressure.

A third small valve *s*″ is placed at the end of the tube *ttt*. It is intended to prevent the water from entering into this pipe from which the steam is allowed to escape. At *r* is a small valve fixed to a lever, and kept closed by a counterpoise, serving, when there be need, to allow the water which may have accumulated in the space E to escape. Finally, a plug R completes the apparatus. It ought to serve to prime the pump before starting.

Suppose we open the steam supply-cock to prime the pump, the two valves *s* and *s′* are open, the latter will suddenly close and raise the flexible part of the diaphragm DD, expelling the water by the valve S′. When this part of the diaphragm attains to the position expressed in the cut by dotted lines, it will raise the central plate. The small valve *s*, freed from the weight of the latter and induced by the spiral spring, which acts upon the knob fixed to its extremity, will close and thus arrest the admission of new steam. The steam included between the castings will continue, however, by its expansion, to expel the water, the motion of the liquid column doing the office of fly-wheel, until the pressure becomes inferior to the atmospheric pressure.

At this moment, the valve *s′* will open, admitting the steam. The latter will raise the valve *s″* and enter the upper part of the pipe BM, when it will become condensed. The steam which escapes from the space between the castings is immediately replaced, at first by water which occupied the upper part of the pipe BM, then by a certain quantity of water raised by suction. The central plate rests again upon the end of the rod of the valve *s*; the flexible part of the diaphragm is applied to the side of the lower casting; in short, when the height of the water column which is raised by suction into the pipe BM has, by its action on the central plate, become sufficient to overcome the pressure of steam upon the surface of the valve *s′*, the latter suddenly opens, and the series of motions already described, recommence and are reproduced indefinitely.

INDICATIONS FURNISHED BY EXPERIMENTS.

In the completed model which was employed for the irrigation of a nursery near Phillippeville, the pipe BM had an inside diameter of $0^{m}10$. The capacity of the space between the castings is about ten litres. The delivery varies according to the pressure of the boiler, the depth of supply, and the height of delivery. It delivered 400 litres per minute to a height of six meters. The suction has been pushed to eight meters. The delivery has been tried only at a height of five meters, but it is expected that it will be able to reach twenty or even thirty meters. The boiler pressure varies from $0^{atm},50$ to $2^{atm},50$. The diaphragm is made of a rubber plate three millimeters thick with insertions of linen. The machine is too new for us to be able to form a sufficient idea of its durability. We think, however, that it will last several months. With it a vessel, charged with water and fine sand, can be pumped without the least trouble.

In view of combustibles consumed, compared with other steam pumps in the vicinity, a slight advantage in favor of an oscillating water column pump seems to be indicated. It has at least one advantage, its simplicity, which will give it preference in many cases; for example, in isolated machine shops in distant places; in works having boilers for other purposes than for motive power, and where one simple steam supply pipe suffices to put the pump in motion, etc.

THE FRACTURE OF RAILWAY TIRES.

By WILLIAM WORBY BEAUMONT, Assoc. Inst. C.E.

Proceedings of the Institution of Civil Engineers.

THE durability of the tires on the wheels of railway rolling stock is one of the most important questions for consideration, as owing to their failure many fatal accidents have occurred, only exceeded in number by those arising from collisions. Thus, in Great Britain, in 1874, the fracture of tires amounted to 55, occasioning the death of 37 passengers and an enormous pecuniary loss to the railway companies. In the twenty-seven years, 1847 to 1874, inclusive, 80 tire accidents were reported upon by the Board of Trade officials, which resulted in the loss of 74 lives, and in 236 cases, of more or less serious personal injury. Previous to 1872, the companies made no return of accidents from the fracture of tires; in that year the number of such accidents was 58, in 1873 it was 30, and in 1874, as before stated, 55. During these three years, however, only those failures which were attended by serious results were reported; but in 1875, every one was systematically recorded. The General Report of Captain Tyler for that year comprises no less than 684 tire failures; and though these resulted in no loss of life, they caused the derailment of several trains. The absence of fatal result is probably due to the great care now exercised in the examination of tires, most of the failures having been discovered at stations.

Various explanations of the cause of these fractures have been brought forward, with various degrees of apparent support from experience. Sometimes the cause has been clearly traceable to a defective weld, or to obviously inferior material, at other times to a reduction of the sectional area of the tire by rivet or screw holes. But when not assignable to these causes, the origin of the fracture has generally been obscure, and its explanation a matter of speculation.

So far as the author is aware, the forces productive of the fracture of the tires of wheels running over smooth and rigid surfaces, have never been satisfactorily investigated. His present object is to point out what seems to be an efficient cause in the production of those strains which must exist in the material of tires prior to their fracture.

The actual cause of fracture, where that has been unexplained at the time of the accident, does not appear to have received much subsequent consideration, and the theories advanced to account for it seem to be untenable upon examination. But it is necessary here to consider some of them, beginning with that which attributes fracture to the strain put upon a tire, by shrinking it on a wheel having a slightly greater diameter than that of the inside of the tire before it is shrunk on. It has usually been assumed that this strain would produce an extension of the tire, equal to the difference in length of the circumference of the wheel body and that of the inside of the tire, before the latter is expanded by heating, for the purpose of being shrunk on to the rim of the wheel. In this assumption, however, the wheel upon which the tire is shrunk, is considered to be perfectly rigid and unyielding; whereas, although it may be—with reference to ordinary considerations—assumed to be rigid, it is not absolutely so, and is in fact, not so rigid as the tire. Therefore, supposing the resistance to compression and to tension to be equal in the rim of the wheel and in the tire respectively, the tensile strain thrown upon the latter cannot be more than one-half that calculated on the above assumption, for the work of eliminating the difference between the lengths of the tire and the rim is done, not upon the tire only, but through double its length, or through that of the tire and the rim together.

If a tire was shrunk on an absolutely rigid body whose circumference was somewhat greater than that of the inside of the tire, the strain upon the latter would undoubtedly be that necessary to produce an extension of its length equal to the above difference; but if the body be compressible, however little, the necessary extension will be reduced, and the strain also. Take, for example, a wheel body with a diameter of 3 feet, and a tire to be shrunk on it with a diameter of 2.995 feet, the difference in the circumferences being 0.1875 inch, and let the tire have a sectional area $A=10$ square inches, and the rim of the wheel an area $a=6$ square inches. Then the increment λ in the length of the tire and the decrement λ' in that of the wheel rim necessary to eliminate the above difference, $(0.1885=\lambda+\lambda')$ in their respective lengths, will be inversely as their areas, or

$$A : : a : \lambda' : : \lambda$$

and

$$\frac{\lambda+\lambda'\times A}{A+a}=\lambda'=0.1178 \text{ inch.}$$

and

$$\frac{\lambda+\lambda'\times a}{A+a}=\lambda=0.0707 \text{ inch.}$$

Taking a co-efficient of elasticity, C, $=27{,}000{,}000$, the strain f and f' necessary to produce the above increment and decrement respectively will be

$$f=\frac{\lambda C}{l}=16{,}906 \text{ lbs.}=7.547 \text{ tons, which}$$

$$\times A=75.47 \text{ tons;}$$

and $f'=\frac{\lambda' C}{l'}=28{,}097$ lbs. $= 12.534$ tons,

which $\times a = 75.26$ tons;

l and l' being the original lengths of the tire and rim, the difference in which causes the above slight difference in f and f'; but as this is eliminated, the strain on the tire and wheel rim will be practically $= \frac{75.47+75.26}{2} = 75.36$ tons. Thus, if the breaking strain of the material of the tire be 25 tons per square inch, the above strain is less than one-third that necessary to produce fracture, leaving on the whole tire a marginal strength of 174.64 tons, even in the case of wheel rims of such large sectional area as that assumed. The radial component of the above circumferential strain on the tire will be that expressed by the relation between transmitted forces (by a curved surface) of tangential tension and radial compression. Lagrange's theorem is here applicable, and may be thus stated:

Let R=radial compression due to T;
T=tangential tension;
r and r'=two radii of principal curvature;

then $$R=T\left(\frac{1}{r}=\frac{1}{r'}\right).$$

In the present application of the theorem, as the tire is circular $r=r'$, and the above equation becomes

$$R=\frac{2\ T}{r}=\frac{2\times 75.36}{18}=8.37 \text{ tons}$$

radial pressure per circumferential inch. With heavy engine wheels these strains would probably be slightly increased, as the rim would be less free to alter its dimensions at the junction with the spokes. But between these, alteration may take place both by change of dimension and form. The resistance, however, to decrement in the length of the rim, and to the necessary radial compression resulting therefrom, is exceeding small in all except engine wheels. This remark applies especially to those carriage and wagon wheels in which the spokes and rim are of flat bar iron bent into segmental forms, the section of the rim not being one-half that assumed. It is not, therefore, necessary to enter into further calculations on this point, as the resistance offered by such wheels to the contraction of the tire must be insignificant in comparison with the tensile strength of the latter.

No account has, however, been taken of the plasticity of the material of the tire, which, especially at high temperatures, allows of its elongation by the force of its own contraction, the residual strain being only equal to the difference between the total force of contraction and that already expended at the higher temperatures in the elongation of the tire; so that even were there a much greater original difference between the diameters of the tire and rim than has been assumed, the resulting strain would probably be little more, as plasticity increases, and the mechanical equivalent of expansion by heat decreases, rapidly, with the rise to such high temperatures as would be necessary to enlarge the diameter sufficiently to get the tire on the wheel.

It would seem, therefore, that the shrinking on of these tires cannot alone result in the production of a strain sufficient to cause their fracture, unless they are of bad material or workmanship. If, however, a strain approaching the tensile resistence to fracture of the material of the tire could be thrown upon it, by the elongation demanded by the difference between the diameters of the wheel and of the tire, the latter should break upon first being put to work, instead of after long wear, as is usually the case. For if that strain were alone the cause of fracture, its intensity would be constantly reduced by the tendency working would have, to make the tire accommodate itself by further elongation. Fracture frequently takes place at several points simultaneously, but it seems difficult to conceive that a simple tensile strain should induce such a phenomenon, as a tire would be relieved of all tension by one fracture, every additional fracture demanding an equal strain for its production. Assuming, however, that the material of the tire is perfectly homogeneous, and of uniform tensile strength, and that the circumferential strain is equally distributed throughout the entire length of the tire, then it is possible to conceive that a strain equal to the tensile strength of the tire could fracture it in several places simultaneously. But unless the above conditions rigidly obtain, absolute simultaneity of multiple fracture would be impossible, and it need hardly be said that practically such conditions never exist. Except multiple fracture take place with absolute simultaneity, it could not occur as a result of tensile strain, for the first fracture would render subsequent fracturing impossible, because it would have dissipated the strain that produced it; so that any further breakage would necessitate the reproduction of a tensile strain slightly in excess of that which produced the first fracture, and for which there is no origin.

By far the larger number of broken tires have been fractured in several places, and of the 80 cases reported upon by the officers of the Board of Trade up to the end of 1874:

9	were fractured at	3	places,	
8	" "	4	"	
5	" "	5	"	
5	" "	6	"	
2	" "	7	"	and
6	" "	in "several places;"		

while out of 14 cases reported by the Great Western Railway Company between 1868 and 1873:

3	were fractured at	3	places,
2	" "	4	"
2	" "	5	"
1	" "	7	"
1	" "	12 or 14 places,	
1	" "	several places.	

Many of those reported in 1875 also broke in several places. This large number of multiple fractures affords strong evidence of the existence of enormous internal molecular strains in the material of the tire, for it seems impossible to conclude, that a tensile strain, or inferiority of material or workmanship, even when aided by impact strain, should be disclosed by such results.

Fracture has as frequently been assigned to the reduction of the sectional area of the tire, by the holes made to receive the rivets, bolts, or screws, by which the tire is fastened to the rim of the wheel. Any such reduction of sectional area undoubtedly lessens the tensile strength of a tire. But unless these holes diminish that strength, by a proportion far greater than that borne by the reduced to the full section, it seems impossible to attribute fracture to this cause alone. In many of the forms of fastening by screws, this reduction in section is very small, for the screw-hole only enters the tire a short distance, and that, in some instances, just under the flange, where the tire is strongest. Even allowing, however, that such holes sufficiently lessened the strength of the tire to cause fracture at these points, it would not explain fracture at several points, nor fracture between two such planes of weakness. Many tires have broken in places where no such planes of weakness existed, the tire being fixed by clips, or by annular clip rings. Again, referring to the reports already quoted, it will be found that out of the 80 accidents in 1874, twenty-three tires were fractured through the solid material, and not through either a weld, or a bolt or screw-hole, although all these existed. Seventeen tires were weldless, and seven were fixed by clips or clip rings, without bolt or screw. Of these, one was fractured in five and one in six places; while the fourteen fractured tires reported by the Great Western Company between May, 1868, and May, 1873, were all affixed by Gibson's fastening. Of the tires that failed in 1875, four hundred and seventy-seven were fastened by bolts or rivets, but of this number only 19½ per cent. broke at the bolt or rivet-holes. These facts prove that the force which initiated fracture was not one of simple tension aided by impact, and that fracture was not due to reduction of sectional area of the tires by the bolt-holes. Further explanation of the nature of the forces productive of the fracture of a tire of good material must therefore be sought.

The alleged reduction of the strength of iron by, as well as the contraction due to, low temperature, has usually been called in to explain the fracture of tires during a frost. The effect of extreme cold upon the tensile strength of iron has not yet been definitely ascertained, though the experiments of Fairbairn tend to the conclusion that the tensile strength of iron, not already 'cold short,' in ordinary frosts in this country, is not materially reduced, a conclusion supported by experience in Russia and Canada, where the cold is far greater and more protracted than in England. The moderate speed of trains observed abroad, compared with that adopted in England, undoubtedly tends to reduce the number of breakages, and the severity of the accidents attending them; but against this may be set, the superiority of English permanent way, and its better maintenance. If the difference in the strength of iron in summer and in winter were considerable, and sufficient in itself to cause fracture of a railway tire, it would be unsafe to travel in any common carriage over many of the ill-laid granite pavements during severe frost, except at low speed. None of the axles would withstand the severity of the shocks delivered through the wheels, at a velocity due to the recoil of a loaded spring, as they pass rapidly from summit to hollow of every inequality of the roadway. Again, so general a cause as frost should be evidenced by corresponding effect, and if productive of fracture of railway tires, it should be manifest by more frequent fracture, and not by isolated instances. Although there seems to be little proof, that the strength of iron to resist static strains is reduced by a low temperature, there is evidence that its power of resistance to impact is somewhat diminished by such a condition, although probably only by a fraction of the extent often assigned to it. If this reduction in strength were sufficient to cause the fracture of one tire in a train, all the rest of the tires of the same train, running under the same conditions of temperature, should be fractured, unless that one tire was of originally bad material, or was weakened by a defective weld or by a bolt-hole. But such has not always been the case, many tires having broken through solid and good material, and not at a weld or bolt-hole, although both have existed in the tire. Again, if low temperature alone could initiate fracture, the lowest temperatures should be most fruitful of such results; so that the intense cold of some countries would be accompanied by such numerous tire and axle breakages, as to make railway traveling almost impossible, except at very low speeds.

Although there is no evidence to show that the occurrence of a moderate frost can by itself reduce the resistance of iron to impact strains, so as to make a tire unable to withstand the shocks brought to bear upon it, there is sufficient proof that frost, in conjunction with other causes, exerts some influence in bringing about a fracture which without it would have been delayed.

Of the 94 accidents before referred to, 17 per cent. happened in the spring, 14 per cent. in the summer, 9 per cent. in the autumn, and 59 per cent. in the winter; thus the number of fractures during the three hottest months has been only 23 per cent. of the number in the three coldest months. But these figures do not correctly represent the comparitive strength of iron under different temperatures; for the hardness of the ground during frost, by diminishing the resilience of the way, and thus converting it into an anvil, may well account for the excess of fractures in the winter, resulting from the severity of the impact strains which the tires have at such times to bear. As a result, however, of the much wider range of observation and systematic record in 1875, the relation given by the above figures is reversed; for in that year fifty tires failed in January, thirty-one in February, thirty-eight in March, seventy in April, seventy in May, sixty-seven in June, sixty in July, fifty-nine in August, fifty-seven in September, fifty-seven in October, sixty-four in November, and sixty-one in December; the greatest number being in April and May, and the smallest in January and February.

Of 61 steel tires which broke on the Moscow-Nishni railway during the winter of 1871-2, the cause of fracture could only be ascertained in 18 cases, the fractured surfaces being rusted; but 8 of these were attributed to inferior metal, 7 to excessive strain in putting on the tires, and three to indifferent quality of metal combined with too great wear. Fourteen tires broke through bolt-holes, and three through screw-holes, while no breakages occurred with the tires on Mansell's wood wheels. Thus the actual cause of fracture can only be considered as ascertained with certainty in about 17 of these cases, the remainder, including most of those in the 18 enumerated, being of unexplained origin. As no breakages occurred with Mansell's wood wheels, and steel tires were more affected by frost than those of iron, it seems obvious that the excess of fractures during winter is mainly due to severe impact caused by the hardness of the way.

The number of axles broken on the German railways during 1873 was 77 in the six warmer months against 68 in the six colder months; and though the winter was a mild one, the fact affords a striking proof of the uncertainty of the alleged decrease of the strength of iron during frost. Were very low temperature by itself so active a cause of the fracture of railway tires, it might have been expected that every frost would have been marked by fractures; but long periods have elapsed with comparative immunity from such accidents, followed by a shorter period marked by their excessive frequency. Thus it was found that the accidents from broken tires reported upon on the Midland railway between 1847 and 1871, a period of twenty-three years, only numbered 5, while between January 1871 and December 1874, or in four years, no less than 10 such accidents occurred on the same railway, that is, double the number in about one-sixth of the time. This proves that the cause must be of slow growth, and that the breaking strain must be so nearly approached, that an unusually severe shock or a slight reduction in strength, such as might be caused by frost, is all that is necessary to complete the conditions of fracture.

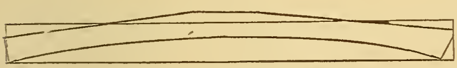
The contraction of a tire during frost has been sometimes supposed to cause its fracture, by throwing an increased tensile strain upon it; but this supposition seems without foundation, for the wheel body is subject to the same conditions of temperature, and the co-efficient of contraction of the materials of the tire and wheel cannot be materially different. Let it be assumed, however, for the sake of argument, that a wheel body, of perfectly rigid material, not subject to alteration in volume by alteration of temperature, is surrounded by a wrought-iron tire, 150 inches long and 10 square inches in section. Suppose now that the tire cools through a range of 20° Fahr., or from say 50° to 30° Fahr., and that its co-efficient of lineal contraction is =0.0000064. Its lineal decrease will then be 0.0192 inch, and the mechanical equivalent of this reduction will be 1.5 ton per square inch, or 15 tons on the whole tire, a strain quite insignificant compared with its ultimate strength, even upon the assumption of the above physically impossible conditions.

The foregoing theories have been most frequently appealed to when the cause of fracture has not been self-apparent; but the Author believes them to be inadequate to explain, first, the fracture of tires of good material and workmanship; secondly, the fracture of tires at several places; thirdly, that a railway may be free from such breakages for a long period, followed by a shorter period of frequent breakage; fourthly, the fracture of tires at several places through the solid part rather than through bolt or rivet-holes; fifthly, that tires generally have run several thousand miles before they fly to pieces.

The strain caused by shrinking on an engine tire, and that of centrifugal force at high speeds, when combined with the loss of strength and the severity of impact during frost, may together amount to a considerable portion of the total resistance of its material. As they cannot, however, be considered sufficient to explain fracture in many cases, the Author will proceed to describe what seems to be the cause of those strains which must exist in a tire at the moment of its fracture; and for this purpose will refer to some well-known facts which, so far as he is aware, have never yet been appealed to.

If a flat stout bar or piece of plate of cast or wrought iron, or other metal, be subjected on one of its surfaces to long-continued light hammering or rolling when cold, that surface will become compressed or elongated to an extent dependent upon the duration and intensity of the hammering or rolling. If the plate or bar be thin the effect of compression by hammering will extend throughout its thickness, and little change will result except of tension in orthogonal directions in the plane of the surface; but if the plate or bar be thick, relatively to one or both of its other dimensions and to the force producing compression at any moment upon one surface only, the effect will be that that surface will be compressed and elongated in all directions, while the opposite surface will remain unchanged. The effect of thus altering the relative dimensions of the two surfaces, of the originally flat plate or bar, will be to make it assume the form of an umbo, or of a bow with the convexity towards the rolled or hammered surface. The amount of this convexity depends upon conditions attending the rolling or hammering, as well as upon the duration and intensity of these. Examples of this elongation of one surface of a plate or bar, and its attendant results of convexity of that surface are not infrequent. A familiar example of its practical application in the foundry, is that of straightening cast-iron plates, such as coping plates which have become bent in cooling, by placing the convex side upon an anvil, and lightly hammering the concave side. Tramway plates, under the rolling action of the wheels of heavily-laden vehicles, afford another example. These, if of sufficient thickness to give the desired protection to a roadway, become converted into shallow inverted dishes. Fig. 1 is a section of a

Fig. 1.



Section of a tram-plate from Westminster Bridge taken up in 1873. The dotted lines represent the original form and thickness of the plate as put down in 1861.

tram-plate put down on Westminster Bridge in 1861, and taken up in 1873, after twelve years' wear. It affords an example of the intensity of the differential strains thrown upon the material of the plate by which the curvature has been effected, because a large portion of the surface has been worn away, chiefly by the aid of the sand and. dirt with which the plates are always covered. This grinding away of the surface of the plate contemporaneously with its compression almost wholly prevents the accumulation of the bending force, for the compressed material which would exert that force is nearly all removed; so that the fact of the production of the curvature of these plates, under such conditions, is a strong proof of the forces brought into play by the rolling action of the wheels of loaded vehicles. Although it took twelve years to produce the curvature shown by the section, a less number of years would, under more favorable conditions, suffice to bring about the same result.

At the time of the Crimean war, a portion of Woolwich Arsenal, traversed by heavily-laden vehicles, was covered with cast-iron plates, for the purpose of protecting the roadways and reducing the draught resistance upon them. After these plates had been down a few months, they assumed the form of inverted shallow dishes, and it was in consequence necessary to take them up. In each of these examples the plate was vertically free, and the force exerted by the extended upper surface was expended in the production of the curvature described. But if the bending thus originated had been opposed by a competent resistance, the internal molecular strains engendered by the extension of one surface, would gradually have become sufficient to cause rupture, either by the crushing of the upper portion of the plate, or by the tearing asunder of the lower portion, just as an arched rib, loaded with a breaking weight, and supported only at its lower extremities, would give way by crushing or crumpling at the upper, or by tearing asunder at the lower edges or flanges. Many more illustrations might be adduced, but it is unnecessary to dwell upon them. It now remains to correlate these facts, and to draw such conclusions as they warrant, in explanation of the conditions involved in the often apparently anomalous fracture of railway tires.

From what has been said, it will not be difficult to see that the rolling and hammering action, to which railway tires are subjected, must so extend and compress some parts of their outer surface, as to create those internal molecular strains, the result of which is illustrated in a small degree by Fig. 1. From the time a tire is put to work, and begins to roll under its load along the hard road of iron or steel, it is subjected to a "rolling out" of the surface at a rate depending principally upon the load, the velocity at which it is impelled, the elasticity of the wheel and the permanent way, and the nature of the material of which the tire and the rails are composed. If the pressure upon a unit of surface of the tire were only such as to bring into play the elasticity of the material, no extension or permanent compression would take place; but as the pressure upon the small surface, at any moment in contact with the rail, is vastly greater than that necessary to surpass the elastic resistance of the material, it loses ductility, and permanent compression, and elongation of the surface are the result.

Every revolution of the wheel is attended by a fresh permanent loss of ductility of the material of the tire; for although repeated application of a similar weight or pressure may not reduce its elastic resistance, the ductility will be drawn upon by every fresh application of the pressure, until all ductile resistance is lost, and rupture approached. Thus film after film of the tread of the tire is permanently compressed and elongated, until the thickness so molecularly altered becomes sufficient to create internal differential strains upon the tire, of such magnitude as to surpass its resistance to rupture, or so nearly to approach it, that an unusually heavy impulse, or other extraneous force, is alone necessary to effect such a result. Considering the small surface of tire at any moment in contact with the rail, and that the load upon this small surface per unit is very great; that the velocity with which the wheel is impelled is often 90 feet per second; and that the speed with which a tire strikes any projection, or descends from one level to another, as at a defective fish-joint, is that due to the recoil of a heavily loaded spring, probably approaching 1,000 feet per second, —it is not difficult to see that the compression of the tread of a tire under such conditions may be very rapid, and a run of a few thousand miles sufficient to create strains productive of fracture. Thus, when the outer and lengthened portion of a wheel tire is under compression, and the inner portion correspondingly under tension, at some period this compression and tension will end in a tendency to tear asunder the inner portion, or to crush or crumple up the outer portion. Or,—as would seem to be more generally the case—these antagonistic forces, in equilibrium while the wheel is running smoothly, will insure the ruin of the tire as soon as that equilibrium is destroyed, by a blow such as is sure to be met with while running at high speeds with heavy loads.

Confining attention for the moment to a tire without weld, and without screw or bolt-holes, it may be assumed that the differential forces are diffused equally throughout the whole length. When, therefore, these forces are nearly equal to the total resistance of the tire to rupture, being elastic forces, they will, on an abnormal shock being delivered upon the tire, cause it to burst, because the forces tending to rupture at every point in its length are thus made to exceed those resisting them, in a time measured by the transit velocity of wave-impulse through a homogeneous material. This is probably not less than 1,500 feet per second, so that the shock may be considered as practically simultaneous throughout the length of the tire. The forces, therefore, which previous to the shock were supposed to be equilibrated by their resistances, being internal, tend, when that equilibrium is destroyed, to produce fracture at every point in the tire. A flat tram-plate which has its upper surface compressed and elongated, being vertically free, can accommodate itself by an upward convexity to the condition of differential surface dimensions; but the circular form of a railway tire prevents any such accommodation by bending. Instead, therefore, of the differential strains being expended in producing change of form, the tire is, in assumed segment, in a condition analogous to that of a bent girder loaded on the convex side by a force which, when aided by a slight shock or other extraneous addition, becomes sufficient to overcome its resistance to rupture.* It will, however, be seen that it is not a necessary condition that every one of several fractures in a tire should take place with absolute simultaneity, because the precedence of one fracture will render those internal forces which produced it free to initiate fracture in as many places as may be necessary to satisfy or expend the internal differential strains. These strains may, when one fracture has taken place, be dissipated by the bending of the tire.

But besides explaining the conditions of fracture of a tire not weakened either by a weld or by bolt, or screw-holes, it is necessary to consider the fracture of tires weakened by these—

* This illustration is not, however, strictly accurate, as the strains in the girder will be greatest at the centre; but with the tire the strains will be uniform throughout any assumed segment.

not indeed to find the explanation of fracture at such points of weakness, for that may perhaps be considered as sufficiently obvious, but to find the reason of fracture when that takes place through the solid material of the tire, and not through screw or rivet-holes.

In the accident at Shipton, in December, 1874, the tire was affixed to the body of the wheel by four rivets. The tire broke at two places, each about midway between two rivet-holes, through the solid material, which was iron, though one fracture was surmised to be at a weld. This is only one of many cases of fracture through the full section rather than through the reduced section at a rivet or bolt-hole. The explanation is not difficult. At a rivet or bolt-hole, the continuity of the tire is broken; and as these holes are usually near the centre of the tread of the tire, the continuity is broken just at the part subject to the greatest compression. The result of this is that round these holes the tangential and transverse compression, produced by the impeded elongation of the material, is dissipated in an upward flow of the particles, tending to the production of a crater-like ridge, somewhat less in internal diameter than the bolt or rivet-head. This ridge is never actually produced, but is worn off either by the ordinary running, or by the break-blocks, as fast as it tends to rise above the normal surface of the tire, which at these points is relieved of almost all strain. Hence a tire, considered in reference to the forces suggested as productive of fracture, may, after it has been some time in work, be stronger at a rivet or bolt-hole, particularly as against impulse, than at a point in the solid material at some distance from it. The above may be thus illustrated: If one end of a piece of iron of small section be subjected to repeated blows from a hammer, the result is, as in making a rivet-head, the hammered particles flow outward in all directions from the centre. But if, instead of the piece of small section, the same amount of hammering be done upon the centre of one surface of a piece of thick flat plate, the work will be consumed in compressing or elongating a portion of that surface, tending to make the plate assume an arched form, because the hammered particles, which were free to move in forming a rivet-head, are confined by the surrounding and underlying unhammered particles in the plate.

The differential strains created in a tire are less simple than have been hitherto considered, for the compression and elongation is most intense toward the centre of the surface, so that the tire is subjected to a transverse strain as well as being, like the centre portions, under compression. In a flanged tire, these strains are more complex, as the flange is not compressed, but, like the interior portions of the tire, remains unaltered except by the tensile strain thrown upon it by the compressed portions of the tread. Thus the tire may be considered as consisting of three portions, rigidly connected, the central portion, under a great compressive strain, being resisted by and tending to lengthen the two others, until the tensile strain, aided by an impact force, becomes sufficient to overcome their resistance to rupture. The conditions indeed warrant the suggestion, that the fracture of a tire is of a character such as is induced by a bursting strain. As a proof of the existence of the strains here appealed to, it may be mentioned that many tires when taken off the wheels present internal transverse curvature, as shown in Fig. 2, though when

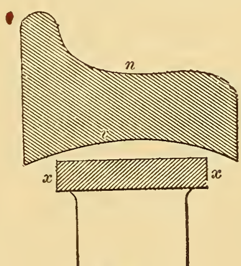


Fig. 2.

the tire was new this surface was flat. This curvature has the effect of keeping many tires tight on the wheels, that would otherwise become loose. Although the rolling of the tire increases its diameter at v, the curvature tends to diminish the diameter at x, x. Of the 684 failures in 1875, three hundred and fifty-nine tires are reported as having split "longitudinally." Of these, twenty-three broke at A (Fig. 3), fifty-eight at B, fourteen at C, seventeen at E, twenty-one at G, and six at K. It will be seen that the number split at B was more than double that elsewhere, the tendency to rupture from the compression of the tread, and the condition of support being greater

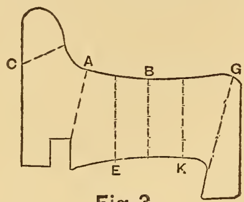


Fig. 3.

at that point than at any other, the static and impact strains being chiefly developed at n, Fig. 2, and the support being at x, x.

It must be pointed out that the conditions brought forward, as to the origin of fracture of a large number of railway tires, do not obtain with the tires of the wheels of ordinary vehicles. In their case, the surface in contact with a macadamised road is always much greater than with a railway tire upon a rail, and the pressure per unit of surface is therefore much less, whilst their running velocity rarely exceeds one-sixth that of a railway wheel, so that the conditions necessary for "rolling out" the surface are absent.

It would seem then that the tires upon elastic wheels have some advantage over those on non-elastic wheels, as the compression of their surface must proceed more slowly than with those upon wheels almost rigid, which act as anvils for the tires to be rolled out upon. Still it is only a matter of greater length of time for them to fail by reason of the internal differential strains.

Having now described what the Author believes the principal cause of the fracture of railway tires, it remains to make a few collateral remarks on the subject. If his theory be correct, however good the material and workmanship of a railway tire, it must gradually become unsafe from other reasons than simple loss of thickness; for, whether it be of steel or of iron, it is amenable to the production of internal molecular strains consequent upon the rolling out and compression of its outer portions, which must at some time become of sufficient magnitude to initiate fracture.

If steel tires or their outer portions could be hardened without sacrificing any of their resistance to rupture by impulse, their durability would unquestionably be greatly increased. The tire would then partake of the character of a hammer with a hardened steel face; the rails upon which it ran would undoubtedly suffer more from deformation of their surface than by unhardened steel or iron ties, but the life of a tire and its resistance to surface compression would, like the hardened hammer face, be increased. The durability of the American chilled cast-iron car-wheels is probably owing to the extreme hardness of their running surface, and their consequent resistance to surface compression. Unchilled cast-iron railway wheels would probably be fractured after running a few hundred miles by the forces described. These views afford an explanation of the cause of the breaking off of small patches from the tread of chilled cast-iron wheels; the detachment of which dissipates the strains induced by compression.

Although the duration of the tire in an elastic wheel is increased, yet as the tire has still to carry a load, its surface must be subject to deformation. That deformation will not proceed quite so rapidly as with a nearly rigid wheel, the inertia of which upon impact strain would have to be overcome by the tire before it was relieved by the springs of the vehicle under which it was running; whereas a good elastic wheel may be considered as having somewhat the character of a spring, and, in so far, being without such inertia. The tires of wheels fitted with breaks probably have their liability to fracture slightly diminished, especially where cast-iron break-blocks are used, as some of the compressed portions are more quickly worn off by these, and by the skidding upon the rails, than with tires not so circumstanced. From this it might be expected that the vehicles of Metropolitan railways, on which stoppage at every few hundred yards necessitates the frequent application of breaks, should be peculiarly free from fractured tires; for a large number of the wheels of every train carry breaks and frequently run skidded for considerable distances upon the rails, so that the wear must be great, and is probably sufficient to dissipate the strains that would accumulate if the tires were not so worn.

The lamination of the surface of rails, particularly noticeable where the traffic is great, is an illustration of some of the effects of the rolling-out action of the wheels. The head of the rail not being wide, and the rolling being as much on one side at least, as at the centre, the portions rolled and compressed are comparatively free to flow towards the sides of the rail, where they become detached, and with rails of inferior quality lamination takes place. Tires of similar material would probably be somewhat relieved by lamination from the strains induced by rolling; but what would be gained in this respect would be more than counteracted by the loss of strength of the material.

With reference to the fastenings for railway tires it would seem, that the ultimate strength of a tire, as against ordinary wear and tear, is not reduced by the method of fastening on to the wheel by rivets or bolts. Of the 550 reported fractures in tires fastened by this means, 79 per cent., or nearly four-fifths, were fractured through the full section; some of which were affixed by screws from the inside of the tire, and only penetrated partly through it. Had these been fastened by rivets or bolts passing quite through them, it is probable that the number of fractures through the solid metal would have been proportionately greater than 79 per cent. Notwithstanding this, however, the best mode of fastening is unquestionably by annular clip-rings and grooves on both sides of the tire, so as to prevent the portions of a fractured tire from leaving the wheel, as it is from the latter cause that the lamentable results of some of these fractures are to be ascribed.

With a view to the prevention of the fractures of tires, the Author ventures to suggest that:—

1st. No tires should be allowed to run more than a certain number of miles, dependent upon the character of the vehicles they are running under, upon the section and material of the tires themselves, and upon the hardness of the rails. At present no sufficient information exists upon which to base an arbitrary mileage, as till recently no systematic accounts of the number of miles run by tires were kept, so that the safe mileage of various kinds of tires under the different kinds of vehicles and engines remains to be determined, by careful experiment and extended observation.

2d. That the condition as to wear of the surface of tires should be watched with the greatest care, and when the yet to be prescribed mileage has been run, the tires should be re-turned, or, if that be not requisite, then they should be heated to a sufficiently high temperature to allow of the dissipation of the internal molecular strains, and of a rearrangement and repose of the disturbed particles. The tires might then, if not worn out, be replaced.

In conclusion, it is not pretended that the statistics in this Paper are complete, as until 1873 the railway companies did not report the accidents on their lines. The figures quoted are of those accidents reported upon by the Board of Trade officials between 1847 and 1873, with the exception of the fourteen by the Great Western Railway Company between 1873 and 1874, and those reported by all the companies in 1875, many of which resulted in no accident. They do not represent all the fractures, nor the number of miles in every case run before each tire was fractured; but they do give, in a large proportion of 550 cases, the particulars and date of fracture, and the mode of fastening, and they are sufficiently illustrative for the immediate object of this Paper.

Although the Author has not been able to bring forward the results of exhaustive experiments and observations in support of the propositions he has made, it is hoped that the arguments he has adduced will lead those who have the means to consider it worth the time and trouble to carry out such experiments and observations.

Dr. Percy observed, through the Secretary, that it did not seem that any real investigation respecting the state of the metal of broken tires had yet been made. It would, he thought, be possible, from a thorough examination of them, to deduce decisive and important conclusions. Some years ago he published a letter in *The Times*, suggesting the desirableness of preserving specimens of metallic objects connected with railway accidents; and he ventured to add that The Institution of Civil Engineers should take up the question, and be the depositary for such objects. There need be no necessity for publicly announcing the particular accidents. The Author had not mentioned Styffe's experiments on the tensile strength of iron at low temperatures. His conclusion was, and he was a trustworthy and an able man, that the tensile strength increased with diminution of temperature. Mr. C. P. Sandberg had also experimented in Sweden on the subject, and concluded that, although Styffe's experiments justified his conclusion when the rupturing force was slowly applied, yet the reverse was the case when the rupturing force was sudden, as in concussive action. Dr. Percy was disposed to think that this view was correct.

Sir John Hawkshaw, Past President, said the Author had brought forward a new subject for the consideration of those who took an interest in the question of tires. He had pointed out that the breakage of a tire might arise from the hammering of the surface; but he thought the suggestion, that a tire should not be allowed to run more than a certain number of miles, was a little premature. In order to come to such a conclusion a strict account would be required, in the record of fractures, of the number of years which each tire had run. If it could be shown that tires broke after a certain age more frequently than before that age, that might be some reason for the recommendation. As far as his experience went no such record had been kept. With regard to the breaking of tires, there were, as in the breaking of links in a chain, an inconceivable number of causes at work, some of which would probably never be discovered. Every now and then a link in a chain would break, leading to serious consequences, though perhaps the chain might have been proved, and care taken that the iron was of proper quality; and this would happen quite as frequently to a new chain as to an old one, indeed perhaps more frequently. Old chains would often go on with fewer accidents of that kind than new ones. So it might be with tires. When he was in the habit of attending to such matters more than at present, he sometimes found tires breaking before any such process as had been described could have acted upon them so as to produce the fracture. He did not say that the process might not occasion fracture; but at all events, before the suggestion was adopted, that a tire should be allowed to run only a certain number of years, a great deal more information was required than was at present possessed.

Capt. Galton remarked that during the last summer he had had an opportunity of seeing many wheels and tires in the United States, which had performed a remarkable amount of mileage; and the conclusion to be drawn from those observations was certainly not that the number of miles run by tires should be limited as a means of preventing accidents. It was, he believed, rather a question of material, and of the cushion upon which the tire rested. A number of Swedish wheels and axles were shown at the Centennial Exhibition at Philadelphia. One set of these was by the Swahammers Bruk Foundry. It was a pair of wheels and axles of welded iron, which had run 125,000 miles (certified in the fullest manner), and they showed scarcely any wear. The tires were fixed on by bolts. Another set of steel tires by the Sandviken Foundry had run about 200,000 miles, with scarcely any signs of wear. The mode of attachment in that case was by a bolt from underneath, penetrating a short distance into the inner surface of the tire. Some steel tires by an American firm had run 309,000 miles, and were not much worn. They were on paper wheels in Pullman's cars, and had been running nearly nine years. The mode of attachment was by bolts passing through the paper of the wheel. The wheel was made of solidly compressed paper, and it appeared exactly like wood. It was formed like a wooden wheel, only the nave and the tires were of metal. Some other wheels used in the United States had afforded very good and even remarkable results. The tire was supported upon a series of blocks of hickory, driven in between the felloe and the tire of the wheel. The blocks were so driven in as just to support the tire, and to keep it free from touching the felloe. The results in point of mileage were remarkable. He thought, therefore, that the chief point for consideration was how to cushion the tire on the wheel, and how to improve the material of the tire, rather than to limit the mileage to be run by the wheels.

Mr. Rochussen said, ten years ago he had presented a Paper to the Institution giving a number of tubular statistics as to the wear of corrugated disc wheels, such as were in general use in Germany and other portions of the Continent. It was then proved that they had a life exceeding 398,000 miles, whilst now, such improvements had been made, that the Bochum Steel Works were enabled to guarantee that the life of these wheels should not be less than 500,000 miles. The plan adopted was to cast the center and the tire in one, so that there was no question as to how the tire should be fastened. If in the end the tire should be worn out, there was no reason why the center should not be treated as an ordinary wheel center, and another tire be shrunk on. The same form was afterwards adopted by the Hoerde Works, and it had been largely introduced throughout the German system,—a wrought-iron center with a puddled steel or cast-steel tire shrunk on, and screwed on from the inside. The latter form was at first found to be cheaper, but now that cast steel was so low in price, there was no necessity to make two separate parts. He believed that the cast-steel wheel now made in this country as well as in Prussia would be the wheel of the day. It seemed hardly dignified, after so many years' experience, still to think of the cushion of a tire, when the tire and the wheel could so well be made in one.

Dr. Pole said the members were much indebted to the Author, who had brought a good deal of thought to bear upon a very obscure subject, and his statements were worthy of careful attention. The facts mentioned with regard to the elongation were well known to those who had an opportunity of observing and examining old tires. The result of the long wear was such that as the tires became thin, all tension ceased, and they actually became loose, assuming a form of section convex to the tread. In regard to the explanation given by the Author of the cause of fracture, there appeared a difficulty, for if it were true, then more tires ought to break. If statistics were given of the number of tires in use, it would be found that the proportion of those that broke was exceedingly small; but the force referred to as occasioning fractures was going on so constantly, that if the Author's explanation was correct scarcely any tire ought to stand. That the force might operate to some extent was undeniable, but the fact of its not acting more generally required some explanation.

Mr. E. Riley thought that engineers should pay more attention to the material of which wheels and tires were made and to the influence the various chemical ingredients had on its quality. He was aware that little confidence was placed in the composition of steel. With regard to wrought iron the question was no doubt chiefly one of mechanical treatment: the iron might be chemically good and mechanically bad. But he believed (and the belief increased with his experience) that the elements found in steel had a marked effect upon the quality. He wished to warn engineers against drawing wrong conclusions on insufficient grounds. He would illustrate his meaning by a case that had recently occurred. He had examined a steel rail, and had found that it contained 0.2 per cent. of sulphur. He could not believe it, but on trying again, the result was the same. The fact was at first doubted at the works, but it was found to be as he had stated. The rail was, he believed, a good one, and an engineer would naturally say, "If you have a good steel rail with 0.2 per cent. of sulphur, what has chemical composition to do with it?" In the manufacture the difficulty would be in rolling. At a high temperature it would be possible to roll it and make it a good rail, but the manufacturer would find a great waste in such rails by ripping and tearing. In all cases of fracture it should be ascertained whether there was anything wrong in the material of the tire or of the rail. He thought that in many instances the material itself might be faulty. He quite agreed that the physical condition of the steel was an important matter. In the case of tires the exact quantity of carbon in each should be ascertained. Engineers might say that they could tell by turning a tire whether it had too much carbon; but he was of a different opinion. The tire might have been cooled slowly, and might contain a good deal of carbon. A great deal depended upon the mode of cooling, especially in rails. He thought that the cause assigned by the Author for the fracture of tires was a very probable one. He hoped that these matters would be investigated thoroughly, and that when failure arose from defective material, it would be attributed to that cause. He was certain, with regard to a rail taken from the Metropolitan line, it might last, yet if submitted to any sudden shock, it must, from its composition, necessarily break.

Mr. J. Baker said he quite agreed with the Author as to the wearing of the outside of tires. In turning up old wheels their outside was sometimes found to be very hard, owing to the compression received during running in contact with the rails, but after getting through the skin the metal was much softer. The chief defect in iron tires was their splitting owing to insufficient welding, they being rolled in a straight bar and bent round in a coil. Some of them were not sufficiently heated for welding. Being worked in a hollow tool caused the edges of the iron to lap outside, and the punch to fill the seams up inside, so that it was impossible to see whether the iron was properly welded, and the compression and bulging of the outside of the tire through running made the defective or unwelded seams give way; but no doubt by this method a strong tire was obtained as regarded tensile strength, the fibre of the iron being the right way to avoid breaking. He believed that frequently the breaking of iron, and especially of steel tires, was owing to tight hooping; some tires were hooped almost to their breaking strain, so that the first sudden shock ruptured them. In many instances his attention had been drawn to the matter, by the spokes or arms of the wheels being bent out of shape by being hooped too tight, and in some cases, when the wheels had been strong ones, a sharp blow with a twelve pound hammer had broken the tire.

Mr. Thornycroft said the cause assigned in the Paper for the breaking of tires, though not perhaps so important as the Author believed, was one that had been somewhat overlooked. A steel plate, three inches thick, eight feet long, and two feet wide, would bend materially by the work of an ordinary hand hammer in a month's time. His firm had employed workmen to flatten steel plates on a steel slab of those dimensions, and it had been the custom to turn the slab over in order to retain a somewhat flat face. The slab was alternately bent one way and another. The insignificant force exerted by a man's arm working on the slab seemed incapable of effecting the amount of bending which is really caused. He differed from the Author in regard to the proposed limitation of the life of a tire to a particular mileage. He believed that the life depended more on the quality of the steel or iron employed than on the mileage run.

Mr. Rich said he knew nothing of the working or wearing of railway tires, but he believed that the action referred to by the Author might take place in other things with which engineers were concerned, and notably in the case of toothed wheels. The surfaces of toothed wheels were subject to more rubbing than tires; an enormous pressure was localised upon a small surface of a tooth in contact, and there was some initial impact, and it might be that teeth were sometimes broken from the gradual extension of their surface under the combined influences of bruising and hammering, and the consequent tearing asunder of their internal parts.

Mr. J. W. Barry thought the great local stress brought upon tires had scarcely been sufficiently considered. A weight of eight tons often rested on a wheel, and as there was but a small portion of metal in contact, the local pressures between the tires and the rails were far in excess of what occurred in any other mode of applying iron. Taking a breadth of 1½ inch or two inches tread in contact at one time, it could not be assumed that there would be more than one-eight or one-quarter inch in width in contact, and under such circumstances there would be a stress of from twenty to thirty tons per square inch. This was the case when the rails and tires were new, but the action was of course increased with worn tires working upon a new rail. Then even smaller portions came in contact, and extremely great local stress was exerted. He thought it was quite possible that

that action might account for some of the failures taking place in such unexpected ways, and at unexpected places. The rail also might be worn in a particular way, so that even with a new tire there might be extreme stress at particular points; and if such pressures were exerted from time to time, the action to which the Author had alluded, of the hardening of the surface of the rail, might be much aggravated. He thought it was extremely important that tires should not be fastened either by bolts or by rivets; for, as the Author had pointed out, an uneven surface was produced, which in spite of the supposed diminution of strain at the rivet or bolt-hole, must lead to an increase of pressure on each side of the hole. Tires running over such points, although wearing away rapidly, would from time to time be exposed, he thought, to greater strains than if the continuity were unbroken. He did not suppose that it would ever be possible altogether to get rid of broken tires; and the important point to be attended to was to keep the broken pieces on the wheel, so as to avoid the serious accidents that happened from such pieces flying out. A short time ago the traffic superintendent of a railway company told him that an express train, which had not stopped anywhere on its journey, entered a station sixty miles from its starting point with the tire of a carriage wheel broken in four places, and the wheel had run on without any one being aware when or where the accident had happened. The wheel was furnished with the well-known continuous ring fastening. If that tire had been fastened by bolts, the probability was that a disastrous accident would have occurred. It was of the greatest importance not to neglect such simple precautions, and to get rid of bolt and rivet fastenings for the tires of railway vehicles.

Mr. J. Cochrane said, in any limitation of the life of a tire to a certain mileage it would be absolutely necessary to take into consideration the speed at which the wheel had been running. If it ran at a high velocity with a light weight, it would be much the same as running at a lower velocity with a heavy weight. With regard to Captain Galton's remarks as to the mileage run by some of the tires on American railroads, it should be remembered that the average speed of trains in America was much lower than in England, and the same might be said with regard to the German railways.

Mr. L. H. Shirley was surprised to hear that the least number of breakages occurred in the months of January and February. He had had some experience in Russia, where the state of things was exactly the reverse, the greater number of breakages being invariably in the winter. On one occasion, on the 3rd of February, 1872, a train started from St. Petersburg to Wilni. In the afternoon there were only a few degrees of frost, but towards the evening the temperature declined to—35° Fahr. In the course of the journey three carriages had to be taken off the train on account of broken tires, and on ascending the steep incline up to Wilna the steel tire of the engine broke. It had been found that wooden wheels answered best in that country, being attended with the fewest breakages. With the ordinary wheel the breakages were numerous, and hardly any great frost occurred without many of the lines being blocked, in consequence of accidents to trains arising from this cause.

Mr. Beaumont exhibited two sections cut from tires, by permission of Mr. W. Adams, M. Inst. C.E., showing plainly the actual transverse curvature that he had described. In reference to the remarks of Sir John Hawkshaw, as to wheels running only a certain number of miles, he did not say that tires should be thrown away, but that after running a certain number of miles they might be taken off and either re-turned or heated, so that the strains due to compression might be dissipated. As to new tires breaking, he had stated in the Paper that if strains from other causes tended to break the tires, such as by shrinking the tire on, it would in that case break when new rather than when old, because the effect of running was to lengthen the tire, and so to reduce the strain thrown upon it by shrinking it on. The same would apply to the observations made by Captain Galton, whose remarks, on the durability of cast iron, tended to support what he had said as to the durability of chilled surfaces, and as to the crumbling away of pieces relieving the strains generated by rolling. With reference to the loosening of tires, he believed that a greater number would become loose but for the bending to which he had referred causing the tire to grip the wheel. After a tire had run a certain number of miles it became worn, and the rim of the wheel was also partly worn, to the new form of the tire. If the tires did not tend continually to assume the transverse curvature described, they would become larger in diameter at x, x, as well as at v (Fig. 2), and would soon become loose; but as it was they gripped the rim at the points shown in the figure.

With regard to the remark of Dr. Pole, as to the reason why a greater number of tires did not break, he thought it was not difficult to give an explanation. A great many tires, after running for some time, not only became curved transversely, but were irregularly deformed, by the detrusion of the material at the tread (Fig. 4), and in that way the

Fig. 4.

strains were dissipated. But in the case of material that was too hard to give way in that manner, the strains were accumulated, and tended to break the tire. Mr. Barry appeared to misunderstand what he had said as to the strain near a hole in a tire fastened by bolts. It appeared that of the 477 cases of fracture mentioned in Captain Tyler's General Report for 1875, in which the tires were fastened by bolts, only 19½ per cent. broke through the holes, showing that the strain round these was dissipated, because the material was there free to flow, its continuity being broken. As to the number of fractures in Russia during severe frosts, he thought that the result was due, not to a difference in the strength of the material of the tire, but to the difference in the hardness of the road during such frosts.

Mr. Stephenson, President, said he must confess that the discussion had not elicited so much information as he had hoped. It was well known by manufacturers that it was a failure not simply in one, but in a great number of important, though small, matters occurring at the same time, that caused the breakage of perhaps the best tires. He quite agreed with the remark that mischief frequently arose from hooping tires too tight; and even when they were so hooped, complete contact was not always obtained throughout the whole breadth of the wheel. He believed that the curvature referred to by the Author was not entirely due to the cause he had assigned, but that it arose in a great measure from the web or spokes of the wheel not being so wide as the tire, the edges being therefore inadequately supported. He believed if the spokes were as broad as the tire, the curvature would be considerably reduced. Another important point had lately engaged his attention in preparing a wheel for the tire. Many persons must have noticed the difficulty there was in getting tools for cutting steel to stand. It was also known that the speed of the wheel on the cutting surface had to be kept low comparatively with the hardness of the metal. It was often found necessary to take a fine cut with hard steel, and sometimes, no matter how well the tool was tempered, a cut was lost. The instrument became at last slightly blunted, and instead of cutting, it was apt to spring and grind; and it was impossible, however experienced a man might be, to get the same cut with the tool after it had once been lost. The change could be easily observed with a microscope. If the man started again, a hollow or a raised surface would be left, and no calipers or templates would set it right. This might be corrected by going over the whole surface with another cut, but generally this could not be done, as the wheel would then be too small. He approved of a cushion between the tire and the boss of the wheel, and he had a strong preference for wood.

Lubrication.—On railway car axles twenty pints of oil lubricate eight journals of cars for 5,000 miles, or one pint for 250 miles.

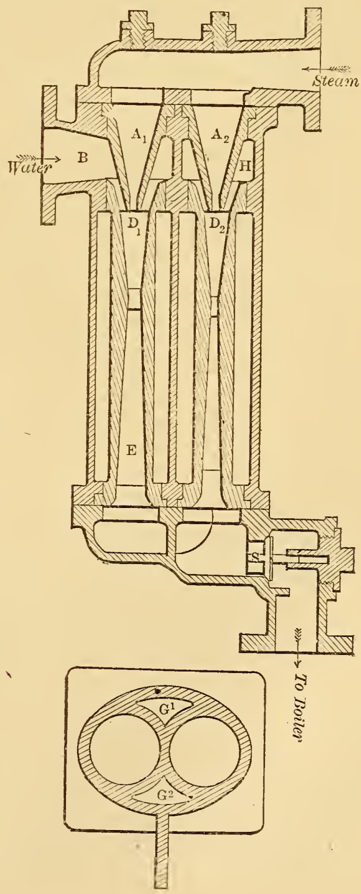
KÖRTING'S LOCOMOTIVE INJECTOR.

From "Engineering."

Locomotive injectors as hitherto constructed labor under the disadvantage of feeding with cold water only, and they can hardly be relied upon if the temperature of the latter exceeds 104 deg. Fahr. Even then they require the most careful adjustment of the water supply. The reasons for this defect may be traced to the principles upon which the injectors are constructed.

With an injector of correct proportions the certainty of action depends upon the velocity with which the water enters the space where the steam and water combine. In locomotive injectors to which the water can flow with only a very small pressure, this velocity depends mainly upon the vacuum produced in the condensing nozzle. This vacuum must be kept as high as possible. With *constant* steam pressure and temperature of water, the vacuum obtained is lower when the condensing nozzle is fed with too much or too little water; in the first case because the jet of steam has not sufficient power to impel the water which gives a back pressure; in the second case because the temperature of the mixture is not low enough, and consequently the vacuum is lessened. For these reasons the water supply requires to be very carefully regulated. With *variable* steam pressures and temperatures of the feed water, the vacuum becomes lower with increasing temperature of water and also with increasing steam pressure, as in both cases the temperature in the condensing space is raised, the maximum of which can be only 212 deg. Fahr. But at this point the certainty of action is *nil*; generally speaking, this temperature should not exceed 194 deg. Fahr. As the increase of temperature with high pressure steam is about 90 deg. Fahr., it follows that the feed water should not be hotter than 104 deg. Fahr. On this account many railways will not allow their drivers to warm the feed water in the tenders, as the reliability of the injectors increases with the coldness of the water, and certainty is of the first importance in railway management. This defect is almost entirely done away with in Körting's universal injector, which works with equal certainty at all pressures. This apparatus consists of two steam jet pumps combined. The second pump or real injector which forces the water into the boiler receives it from the primary or assistant injector under pressure, so that the second pump has only to overcome the difference in pressure existing between that of the boiler and that already overcome by the primary injector.

The required quantity of steam is therefore divided, and only a small portion of it used in the first part of the apparatus. Consequently the increase of



temperature is much less than in ordinary injectors; the water entering it may therefore be much warmer without bringing the temperature in the condensing space above 194 deg. Fahr., which is the maximum here as in ordinary injectors. The temperature of the feed-water may safely be as high as 158 deg. Fahr. A special feature of this primary injector is that with increased steam pressure it delivers, without regulation, more water at increased pressure to the second part of the apparatus.

The second pump delivers into the boiler the water forced into it by the primary injector. The certainty of action of this second part of the apparatus depends upon the pressure with which it is fed by the assistant injector and not upon any vacuum. As with increasing steam pressure the velocity of the water entering the second pump is also increased, it follows that with the same temperature of feed-water, the reliability of this apparatus remains the same under all steam pressures, while with ordinary injectors it decreases as the steam pressure increases. On this account no water regulation is necessary. The temperature in the condensing space does not come in question with the second part of the apparatus; it may, if required, exceed 212 deg. Fahr., and in fact does exceed it, for with feed-water of 158 deg. Fahr., and 120 lbs. boiler pressure, the water fed into the boiler is actually 257 deg. Fahr. The apparatus therefore must not be provided with an overflow communicating with the atmosphere, as otherwise the high temperature would cause the formation of steam and an escape of water. The apparatus is started by opening a small cock behind the injector, similar to that with which other injectors are provided for letting the water out of the pressure pipe.

The foregoing illustration shows the Körting universal injector in longitudinal and cross sections. The working steam simultaneously enters the two steam nozzles A_1 and A_2 in the injector. The jet of steam from A_1 draws the requisite water through the pipe B, and forces it through the cone D_1 with corresponding velocity. This velocity is transformed into pressure in the diverging tube E which communicates by means of the chambers G_1 and G_2 (see cross-section) with the space H of the second pump. From here the water enters under pressure the condensing space D_2, whence it is forced by the steam issuing from the nozzle A_2 into the boiler through the back pressure valve S. While starting the injector a cock communicating with space E_2 is opened till water escapes from it, after which it is slowly closed.

THE MEASUREMENT OF FORCE.

By DE VOLSON WOOD, M. A.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

It is rare that an assailant supports an antagonist while he proceeds to treat him with unmerciful blows. In this regard I am fortunate in falling into the hands of Mr. Robert Moore. He quotes my expressions with as much confidence as if I were reliable authority.

Whatever be the main purpose of his paper, as published in the preceding number of this Magazine, some points are evident, a few of which I will notice.

He states that I have assigned as a reason for my position that "the pound measures pressures, as well as motions" (p. 336). Where have I stated that the pound measures motions?

He states (p. 338) that I object to the use of the absolute unit of force. Where have I objected to it? Further on he commends me more than once for having used the algebraic expression which represents it.

Mr. Moore claims that momentum is a general measure of force, and in attempting to prove it makes no discrimination between "Momentum" and "Momentum-increment," a fallacy which, I think, Prof. Clerk Maxwell will not be guilty of. Prof. Maxwell's statement, as quoted, is true only for a force acting with a constant intensity.

Mr. Moore seems to object to the pound, that is, the pound of force as a proper measure of force. I say *seems* (these are the only italics I have in this article), for I inferred this from one of the earlier declarations in his article, but if that is his position he has contradicted it in several places. I contended that the pound was the more simple expression, and to show how nearly Mr. Moore agrees with me I quote from his article (p. 339): "We have just seen, the pound and the absolute unit are exactly the same in kind. Both are forces, and there cannot possibly be anything measurable in terms of the one which is not equally measurable in terms of the other. . . . For some reasons the pound is the more convenient unit. It is more generally known, and does not involve as high numbers as the other. But aside from its convenience it has no superiority whatever." I would like to underscore some of that.

He refers to one error, the correction of which is so evident that I would not think of referring to it, had he not called for an explanation from me. It is only necessary to say that "acceleration" should be substituted for "velocity," and otherwise it is immaterial whether the blunder were made by the printer or by myself.

In the expression Mv, if M represents a certain number of pounds of mass and v the velocity in feet per second; then, if Mv is not a certain number of foot-pounds of momentum, what is it?

As illustrating the looseness of Mr. Moore's expressions, I notice that he not only calls "pressure" "force," and "that which produces motion" "a force," but he also calls the "horse-power," "force," and "weight," "force." In reference to the last, he says "weight is not matter but a force acting upon matter." This may, however, be a printer's blunder.

STEEL MAKING BY A NEW PROCESS.

From "The Engineer."

Steel is so important an element in all engineering operations that any efforts which may be made towards effecting substantial improvements in the method of its production cannot fail to be watched with interest, and a new process which is being brought before the public by the Red Moss Metal Company is certainly worthy of attention. This new process, which is described as "a method of producing pure charcoal steel directly from the ore," is the invention of Mr. Henry Larkin, of Manchester, who has devoted some five years to the perfection of the various details, and these we have had an opportunity of inspecting in the several stages of the manufacture in the works now in operation at Warrington. Before, however, describing the process, we may state that the chief object of the inventor has not been to produce what may be termed a cheap steel, or to compete with either the Bessemer or the Siemens-Martin process on their own ground, but primarily to secure purity and accuracy in the production of a high-class tool steel, although at the same time he claims to have effected such economies by his special method of manufacture as to enable the company to compete in the market on the basis of price as well as of quality. The method adopted differs essentially from the ordinary routine of smelting, puddling, rolling, and converting into blister steel, the aim of the inventor being first to secure a pure powdered metal, and then to convert this directly into steel by the agency of pure carbon and uniform treatment, which, as seen in operation at the Warrington works, may be described as follows:

The first operation is the crushing of the ore, which we may add is obtained from the Marbella Mines on the coast of Spain, on account of its magnetic properties, an essential although not an absolutely indispensable feature in connection with the process adopted for removing all extraneous and impure materials. The crushing is effected by passing the large and small lumps of the ore first through the jaws of one of Blake's machines, set as closely together at the bottom as practicable, the crushed material being sifted as it falls, and the coarser portion then passes through a disintegrator. In this way the whole bulk of the ore is reduced to the condition of iron sand, mixed of course with the gangue of the ore; and the next step is to separate the actual ore from all extraneous matter, for the purpose of obtaining as nearly as possible a pure oxide of iron. This is effected by an ingeniously contrived self-acting magnetic separating machine, specially devised by Mr. Larkin for the purpose. In this machine, which is capable of dealing with large quantities of material, the particles of magnetic oxide are picked up by magnetic attraction contained in a pair of revolving drums studded at intervals with horseshoe magnets, and carried into their proper receptacle, whilst the refuse is deposited in another. Having thus got as pure and rich a material as possible in a powdered condition, the next operation is to mix it thoroughly with a sufficient quantity of powdered carbonaceous matter to combine with the oxygen of the ore, and thus effect its reduction. Powdered charcoal and resin, or other suitable bituminous substance, reckoned together somewhat in excess of the oxygen to be removed, is the carbonaceous matter employed, and the mixture, after being slightly warmed and compressed into blocks in an ordinary brick press, is ready for the reducing furnace. This furnace consists of a series of ⌓ shaped gas retorts, with doors to open at each end. The retorts are heated by a fire acting somewhat on the principle of a Siemens' gas producer, and are supported throughout their entire length by an intricate arrangement of brickwork, which also serves to prevent a too ready escape of the hot air into the flue. The burning gases from the fire are also made to completely envelope the retorts by being carried over and under in a zig-zag course, thus still further delaying their passage and arresting the heat with which they are charged. At regular intervals air-holes are opened in order to complete the combustion of the gases as they circulate round the retorts, thus securing the greatest heat where it is actually required, and at the same time complete combustion of the fuel used. The retorts being ready for the charge, the door is removed from the feeding end, and a small stack of the pressed bricks of ore and carbonacous matter, packed closely on a rectangular iron plate, is pushed in by means of an iron rod. The plate being then withdrawn, the stack of bricks is left securely placed, and a second and third feed immediately follow, filling the retort, which is at once closed. After having been exposed to a pretty full red heat for nearly twenty-four hours, gas will have ceased to be given off, the carbonaceous matter will have become practically consumed, and the oxide of iron converted into red-hot iron powder. This having been accomplished, the next important step is to convey the red-hot powder from the retort without exposure to the action of the atmospheric air, and to keep it so until it is cooled. This was an operation at first surrounded with considerable difficulty, but is now accomplished by Mr. Larkin in the following manner :

The charge being ready for removal, ordinary coal gas is first, by means of pipes provided for the purpose, turned on into the inside of the discharging end of the retort in order to produce a full outward pressure of gas, whilst the discharging door, which is at the underside of a projecting end-piece of the retort, is removed. The door being thus removed, an iron receiver is brought up closely under the projecting end-piece and securely supported there. By a similar arrangement of pipes gas is now also let into the inside of the feeding end of the retort, when the door of that end is quickly removed and a temporary door with a wide slot half way down the middle is put in its place. Through the slot in the temporary door the discharging tools are introduced, and the red-hot powder is quickly pushed forward into the receiver placed at the discharging end. As soon as the retort is empty the gas at both ends is turned off, and the iron receiver containing the metallic powder is removed, and kept carefully closed until its contents are cool. When the metallic powder is sufficiently cooled down, and no injury can arise from its exposure, it is turned out of the receiver and again passed through the disintegrator and magnetic machine for final purification. This practically completes the special process patented by Mr. Larkin, the only remaining operation being the mixing with the pure metallic powder thus obtained, whatever additional carbon may be needed, chiefly in the form of resin, which enables the powder to be pressed into cakes, in which form it is passed into the crucibles and is melted in the usual way, with the addition of manganese or any other alloy that may be found advantageous.

At first sight the multiplicity of operations involved in the process would appear to present a serious disadvantage, but they are almost all of them of so simple and automatic a character that they require little more than careful attention, and accuracy in weighing and mixing to insure success. And although from the description we have given it will be seen that it is scarcely a correct use of terms to speak of the steel as being made direct from the ore, the whole of the operations are carried on within the works, and can, we are informed, be completed within the space of four days; or, in other words, the company can within that period receive into their works the raw material and manufacture it into steel bars according to the specifications which their customers may require.

The works of the company have been in operation for about two years. Although the production up to the present time has been only on a comparatively insignificant scale, the experimental period may be said to have been fairly passed, and the most important feature —the successful application of the process—has now to be considered. The manufactured steel has been subjected to a number of tests, and the results of these furnished us by the company have certainly been of a satisfactory character. Its adaptability for engineering tools has been tested in the workshops of the Great Eastern Railway Company; where in turning cast steel tires, we are informed, it has got through at least double the work of any other description of steel which has been tried, whilst still more satisfactory results have been obtained by Messrs. Hobbs, Hart, and Co., the lock and safe makers of this city. For ascertaining its toughness and capability of sustaining great tensile strains, a series of tests has been made by Sir Joseph Whitworth, of Manchester, and the following tabulated statement will give the results:

Class.	Pressure first permanent alteration.	Breaking strain per square inch.	Total elongation.	Elongation per cent. showing ductility.
Mild tool steel.	T	T		
A1 No. 1	28.86	52.74	.4626	23.13
		Chisel steel.		
A1 No. 2	31.84	46.77	.4896	24.48
		Chisel steel.		
A2 No. 3	41.79	69.65	.2236	11.18
A2 No. 4	33.83	59.70	.3185	15.92
Hard tool steel.				
B1 No. 5	39.80	64.68	.3134	15.67
B2 No. 6	40.80	63.68	.2725	13.62

So far as its success as a commercial undertaking is concerned, the results have not as yet been so satisfactory to the company. Experience has had to be paid for after the usual fashion, and the various processes have only been perfected after costly experiments, whilst the limited quantity of the manufactured article which the company have been able to place on the market has scarcely been sufficient to cover the actual outlay in production. Having now, however, as we have already stated, passed the experimental period, the company feel prepared to compete in the market with best makers of steel, and if they can continue to command the same satisfactory results as those already reported, there is no reason why they should not do so with success.

THE POSITION OF ARCHITECTURE.

By Mr. J. A. PICTON.

From "The Builder."

Let us take a general survey of the state of architecture over the civilized portion of the world. During the last half-century an enormous change has taken place.

The mighty power of steam, whether applied to manufacture or to locomotion by sea and land, has broken up the old lines and established new channels of thought and progress: no arts have felt the change more than engineering and architecture. In the seats of ancient civilization, whether at home or abroad, the old towns have been renovated and rebuilt. Paris, usually considered the center of the arts of civilized life, is the most eminent example. Under the auspices of the late Emperor and his henchman, Baron Hausmann, the city over nine-tenths of its area has been rebuilt; districts of squalid, tortuous alleys, the abodes of fever and the hotbeds of insurrection, have been replaced by stately arcaded avenues and boulevards lined with trees, faced with handsome stone-built mansions, hotels, and public buildings. Never in the history of architecture has there been such a transformation within so short a period. On the whole the effect is decidedly good. There is nothing in the way of street architecture equal to that of Paris, whilst the taste displayed in the vistas and intersections, and the open *places* where these occur, give a piquant charm not to be found, to the same extent at least, in any other city. Some of the public buildings and churches are of a very high class. The New Opera House, the culminating point of modern Paris, is doubtless open to criticism; but for lavish expenditure and grandeur of interior effect it will be hard to find its equal. The impulse thus given to Paris has spread over the whole country. Quiet Mediæval towns, which had slumbered on for countless ages in picturesque stagnation, suddenly awoke with a burning thirst for improvement and progress. Not only the great cities, such as Marseilles, Lyons, and Bordeaux, but Rouen and Rheims, and Orleans, and their sister towns in countless numbers, even to such a relic of the olden time as Avignon, have been rooting up their Mediæval features, destroying their old buildings, and converting their streets into a *réchauffé* of modern Paris.

The spirit of progress in architecture has not been confined to France. All over Europe, in every town of importance, the same revival has taken place. Vienna has built a new town over the ancient ramparts between the old city and the suburbs, and adorned it with many noble buildings and works of art, amongst which may be mentioned the New Opera House and the Votiv Kirche, structures fit to take rank with the noblest works of modern times. Italy, the home of architecture and art, is pressing on in the same direction. Milan possesses a unique feature in the magnificent Galeria Vittorio Emanuele, connecting the two principal squares, the Piazza della Scala and the Piazza del Duomo, erected within the last few years. Genoa and Florence are following in the same track; and Rome, the Eternal City, as she is called, has taken a fresh start, and is vigorously pursuing a course of improvement, which has already enhanced the value of property to an almost fabulous extent.

Our own country, as you all know, has not been behind in the race. Here our progress has been further stimulated by the sanitary movement, which has led to very important consequences, never originally contemplated. The metropolis, as was natural, took the lead, and is still working energetically, opening out new streets, pulling down objectionable quarters, and re-arranging them with an eye both to health and beauty. Amongst these metropolitan improvements two are worthy of special mention—the Holborn Viaduct and the Thames Embankment,—which structures are each in their several way amongst the finest of modern times. Others of our great towns have kept abreast of the movement. Glasgow is engaged in a noble scheme for the reconstruction of the lowest portion of the city, and Birmingham is about to spend two millions sterling in rendering the town worthy of its high position in the country.

The wealth of the nation has prodigiously increased of late years, and has been liberally expended in the direction of architecture. This is seen in the increased attention to design, and in the quality of the materials employed. The vile covering of compo, which half a century ago was all the rage, and was a mask for the most wretched material and work, has almost entirely disappeared, and is replaced by honest brickwork and ornamental stone facings. The architect has wider scope for the display of ability, and more is expected from him. The houses of our gentry and merchants at the present day display an amount of comfort and elegance which a century ago were never dreamt of, even in houses of much higher pretension.

The People's Park has become an institution in most of our large towns, and has done much to neutralise the squalidity of our lower quarters, and to brighten the life monotony of our industrial classes. Architecture, to a certain extent, has lent its aid in their embellishment.

In Liverpool, commercial buildings on a large scale have become a prominent feature. Insurance offices, banks and piles of mercantile buildings, occupy the best situations in our leading streets, and take the place with us of the palazzi in Rome, Florence, and Genoa. The exigencies of commerce require a peculiar treatment. Light, which in Italy is rather something to be avoided, with us is the most essential element. Whatever our buildings may thus lose in dignity and grandeur, they may gain in cheerfulness and brightness of aspect.

The introduction of the suburban park has naturally led to a superior class of suburban dwellings. We find this the case everywhere. In our own town a fringe of noble mansions is gradually surrounding Sefton Park. The styles adopted are fairly open to criticism, but in the amenities and elegancies of life they will be found quite equal to the demands of modern luxury.

Shop and street architecture has hardly made the same advance as the departments I have alluded to, but there are even here signs of improvement which are full of promise. The new streets in the City of London have many façades of great beauty, and the street architecture of the West End, where stone and brick have replaced cement, exhibit a wonderful advance over the fashionable squares of half a century ago.

There is one department of modern art to which I desire to make special allusion—I mean the architecture of engineering. In the olden time the architect and engineer were one and the same person. Leonardo da Vinci, Michel-Angelo, and Albert Dürer were painters, architects, and engineers, In modern times, however, a separation has taken place. The architect is confined to buildings properly so-called, and to the engineer is confided the execution of works supplying the public wants where durability and strength are required. In these respects our modern engineering is unsurpassed. The old Romans, with all their constructive power, and it was vast, never executed any works equaling the docks of Liverpool, or the London & North-Western Railway. It is much to be regretted that æsthetically there should exist almost universally such an utter want of taste in carrying out our engineering works. In many cases where a very slight or probably no additional expense would have crowned a noble work with the finishing grace of beauty, the opportunity has been neglected or even ostentatiously rejected. Could anything, for instance, be more utterly hideous than the railway bridge, erected by Brunel, over the Wye at Chepstow? Look at the Albert Dock warehouses at Liverpool, consisting of a noble mass of building fronting the river with breaks and projections, only requiring the hand of genius with a few graceful touches to stamp it with the character of dignified beauty. It is now merely a huge mass of deformity. I may also refer to the railway bridges over the Thames, leading to the Cannon Street and Charing Cross Stations. The bridges in every great city spanning a river are a great source of picturesque beauty. The graceful curves of the arches, the proportions of the piers, the opportunity for tasteful ornament, have rendered them a favorite study with architects in all ages. Paris and Florence are justly proud of the effects produced by their numerous bridges, and London Bridge, Waterloo and Blackfriars have always been considered as adding materially to the beauty of the metropolis. The railway bridges over the Thames, which I have mentioned above, are about the most conspicuous examples of ugliness and pretence to be found in the country. Turn your eyes again to the two bridges over the Menai Straits. Thomas Telford was an architect before he was an engineer, and had executed buildings in which considerable taste was displayed. His Bangor Suspension Bridge is a model of lightness and beauty, of strength and grace. Compare that with the Britannia Railway Bridge, its neighbor, where the highest engineering talent, combined with unlimited outlay, could devise nothing better than a square hollow beam. I must, however, in justice mention a more recent work nearer home—the Railway Bridge at Runcorn—which has to a considerable extent redeemed the charge of want of taste made above. The lattice, which is the only true principle for structures of this kind, has been very skillfully applied with very good results. There are few things finer of its kind than a distant view of this bridge, with the graceful sweep of its arcaded approaches on each side.

There is one recent engineering work which may be mentioned in terms of unqualified praise; I mean the Thames Embankment. It is a work worthy of the metropolis of a great empire. It has converted into a source of beauty and utility a site which was previously a byword for deformity and wretchedness. The grandeur of the design, and the magnificent way in which it has been carried out, are worthy of all commendation.

There is one department of engineering which affords abundant scope for beauty and design, viz., the Railway Stations. In some of these—*par excellence* the Midland Station at King's Cross—the aid of the architect proper has been called in, but the vast majority have been left to the same hands which designed the retaining walls and set out the embankments. The results in some cases has been grievous disappointment that so fine an opportunity for artistic display has been lost. At the same time many of the roofs over the stations possess the elements both of grandeur and beauty, from the vastness of the span and the scientific mode of their construction. Amongst the most noteworthy stand out the roof over the Midland Station above alluded to, and the most recent construction in Lime Street, Liverpool.

The revival of Mediæval architecture naturally led to a closer study of our old buildings, particularly the ecclesiastical ones, which were suddenly discovered to be in a state of decay, discreditable not only to those who had the charge of them, but to the nation at large. This having been seriously enforced on the public, an enthusiastic feeling set in towards their restoration; and the work has been carried on most zealously for a number of years. The amount of funds raised for this purpose by the liberality of the public is a marvelous sign of modern times. This result has been one of a very mingled character. In one point of view, the idea of restoring a cathedral to the appearance it presented in its palmy days, when it was turned out fresh from the hands of the freemasons of old, is one to be commended, but in other aspects it cannot be looked upon without a sigh of regret. A great part of the charm of ancient buildings consists in the association of ideas, in the feeling that we are gazing on the very stones which were put in their places in the days of the Plantagenets or the Norman kings. We feel identified with the ages past and gone when we look up at the glorious roof of Westminster Hall, and reflect what chequered scenes of English history have been enacted under its shadow. But scrape the rust of antiquity from the stones, replace the woodwork by an exact *fac-simile*, and the charm is fled. The flavor is gone; we are gazing on a substitute instead of the original, the link of connection is broken and can never be replaced.

I am quite aware that in many cases this is inevitable. Where the substance is so far gone as to be incapable of repair, it must of course be renewed; sentiment must not be allowed to stand in the way of urgent necessity. But where it is at all practicable, I would plead for tenderness with the old work. Let it be replaced stone by stone. Let the venerable rust be disturbed as little as possible, that we may feel that we are united with our gallant sires of old, not only by sympathetic historical associations, but by a tangible chain uniting us link by link with all that is great and picturesque in the past. Who would wish to scrape the interior of Westminster Abbey or of Henry VII.'s Chapel?

> "If such there be go mark him well,
> For him no minstrel raptures swell."

The highest position would not preserve him from the execration of every one with the soul of patriotism within him.

This spirit of renovation is not confined to our own country: it rages with even a more thorough fanaticism in France and Germany. Time was when the city of Cologne, with its host of venerable churches, seemed like a section of the Middle Ages drifted down to our own times. Visit it now. The moss-covered façades, with their mildew of ages, are scraped and chiselled out of all connection with the past. The brick-work looks as if it had just been turned out of the contractor's hands. We turn away with a sorrowful feeling, something like that expressed in the old Scottish song:

> "O, this is no my ain house,
> I ken by the biggin o't;
> For boro-kail thrave at my door-cheek,
> And thristles on the riggin o't."

Closely akin to this question of restorations, is the propensity for the polychromatic decoration of old buildings. On the Continent this unfortunate propensity has had the effect of obliterating, or at least of concealing from view, the most characteristic features of some of the most interesting relics of antiquity. In England the principal object to which the advocates of polychromism have directed their attention is the decoration of the interior of St. Paul's Cathedral. Several gorgeous designs have been produced, but they have made very slow advances towards securing public opinion. A very rich and glowing effect may no doubt result from lining the building with coloured marbles, mosaics, and gilding, but it would no longer be the St. Paul's of Sir Christopher Wren. The effect of the design was intended to be brought out by harmony of proportion, beauty of form, due play of light and shade, and a moderate amount of sculptural decoration. Three of these elements would be entirely ignored by the introduction of the style proposed. Where richness of material and glow of color are the main sources relied on, mouldings and sculptured features are altogether out of place. Flat surfaces as a ground for the ornamental material are all that is required. Thus at Ravenna, where mosaic is so profusely introduced, at St. Mark's, Venice, and at San Paolo without the walls at Rome, the costliness of the material dispenses with elaborate architectural details.

The nature of the material should have some reference to the locality in which it is to be displayed, particularly in exterior decoration. Works of art in marble, and richness obtained by color and gilding, in the dry atmosphere and cloudless skies of Italy and the South, may keep their brilliancy for ages, whilst when exposed to the murky atmosphere of London or Liverpool, charged with humidity and soot, a very short time is required to destroy their beauty and precipitate their decay. It is grievous to see many beautiful and costly monuments in our cemeteries, of a date comparatively recent, with their surfaces corroded, their sculptures dropping to pieces, and their inscriptions obliterated. Gilding, color, and metallic decoration fare little better. Iron will rust, gold will tarnish, color is soon begrimed with soot. The introduction of polished granite, whether gray or red, has been a great boon for monumental purposes, combining color, beauty of surface, and durability. It is somewhat surprising, considering the vast advances which have been made of late years in the art of pottery, that terra-cotta has not been more freely introduced for architectural and monumental purposes. In Italy, in the sixteenth century, it was freely employed with excellent effect, as may be seen by the examples at the Certosa near Pavia, the Ospedale Maggiore at Milan, at Bologna, and other places. Perhaps the most beautiful specimens of the kind are the friezes or panels on the façade of the Hospital at Pistoja, by Lucca della Robbia, which combine beauty of form, color, and durability, to an extent unapproachable by any other material.

The literature of our art would require a treatise to itself. I need not refer to the standard works, such as Vitruvius, Palladio, Leoni, Chambers, Stuart, Britton, Pugin, &c., which are familiar to every student. Architectural literature in more modern times has not been found wanting. At the head of recent writers we must undoubtedly place M. Viollet le Duc, whose multifarious works, commencing with the "Dictionnaire Raisonné d'Architecture," down to his most recent volume, "Histoire de l' Habitation humaine," are replete with the most valuable information, and illustrated with a profusion and correctness not previously found. The magnificent work on Rome, by Francis Wey, though not entirely architectural, may be consulted with advantage for its beautiful illustrations.

In Germany, the "Geschichte der Architektur," by Lubke, gives a comprehensive view of the art, and is particularly valuable for its illustrations of German buildings.

In England, Mr. Fergusson's works are too well known to require more than a passing reference. His most recent volume on the Architecture of India supplies a missing link in the history of the art. The numerous works of Mr. Edmund Sharpe have afforded most valuable aid to the students of Gothic architecture in its practical application. Nor is it likely that the supply of architectural works will diminish. The facilities for illustration are now so numerous, with the aid of photography, lithography, and improved methods of engraving both on wood and metal, that scarcely an architectural example of the slightest value will long remain without illustration. In this slight survey of the literature of architecture, it would be unpardonable not to make honorable mention of the periodicals. The *Builder* has pursued its useful course for about thirty-four years, and has disseminated an amount of information quite incalculable. The *Building News* is remarkable for the profusion of its illustrations. The *British Architect and Northern Engineer* is pursuing a useful course in our own neighborhood. In France the *Revue Génerale d' Architecture*, edited by M. César Daly, and in Germany the *Architektonisches Skizzenbuch*, will keep the reader *au courant* with the most recent designs and erections. I am not acquainted with any American periodical devoted to architecture, but I perceive in the report of the recent National Convention of the American Institute of Architects, in November last, that a weekly architectural journal was announced to commence on the 1st of January in the present year. The interchange of these various publications from country to country cannot but exercise a beneficial influence in the interests of the art.

In taking a general birds-eye view of the state of architecture in the civilized portion of the globe, we find great divergencies. Each nation has its own peculiar tendencies and idiosyncrasies. It would be almost impossible to mistake a German for a French building, or either of these for an English one. Much of this arises from the different habits of the people, and this again is dependent to a considerable extent on climate. In Italy the buildings are arranged to keep out heat; in Russia and the northern parts of Europe the object is to keep out cold.

The *motif*, therefore, the principle of design in each case, starts from a different center, and has widely different aims. So, again, in church building. Protestant Prussia models her churches on an entirely different principle from Catholic Austria. The orthodox Greek ritual imposes on Russian churches a mode of arrangement entirely different from both. France and Italy, of course, preserve in their church building the original basilica form. England is the only Protestant country which adopts the Mediæval Catholic arrangement for its churches.

Again, in domestic architecture, the tendency of the people to live in self-contained houses, on the one hand, or in the flats and apartments of a large mansion, on the other, has very marked and important influence on the style of building and the appearance of the towns. The stately streets of Paris, with their six and seven storied *maisons*, each with its *porte cochère* and inner quadrangle, contrast very favorably with the interminable ranges of three-storied houses in London. The second-rate towns in France and Germany present a still more striking contrast with the country towns of England in the loftiness and scale of their habitations.

Climate also, as affecting social habits, exercises a powerful influence on the laying out of towns. Where the people can enjoy out-door life for nine months in the year for the most part in bright sunshine, the arrangements must necessarialy vary from those in a country where fog, and rain, and mist, are the normal condition. The blooming gardens interspersed amongst the houses, the trees lining the streets and quays, the parterres of flowers in every open space, which distinguish Italy and the south of France, would be an anomaly in Scotland or Sweden.

Another cause of diversity in architectural displays is the great difference of material found in different countries and districts. The center of France, and the province of Normandy, possess freestone of the finest quality in the oolite formation, and their architecture has profited by the boon, in the refinement and beauty of their cathedrals and public buildings, and in the care bestowed on their private mansions. Brittany and the north-west of France is almost entirely a granite district, the result of which is found in the massiveness of the architecture, and its plainness even to sombreness. Compare again the brick architecture of Flanders and Holland, much of which combines richness and beauty, with the timber buildings of Switzerland or Norway; or the dull brick buildings of most of the English towns, with the stone ashlar fronts of Edinburgh or Glasgow, and it will be seen that the nature of the materials at hand exercises a most important influence on the nature of design and construction.

To a great extent the modern facilities of carriage have neutralised advantages and disadvantages of this kind, whilst invention is ever at work to furnish new materials and increased opportunities for the architect. The vast improvements in the manufacture of iron and glass have furnished the means of combining lightness and strength to an extent previously unknown. This has already manifested itself in the variety of Crystal Palaces already erected, and is destined to effect ere long still greater changes in the art of building.

To what should all this lead? The architecture of a people is the expression of its life and thought. The character of a nation is stamped upon its buildings. In the Egyptian, the Assyrian, the Greek, and Roman structure, we find indelibly fixed the despotic gloom of the first, the gorgeous state of the second, the elegance and grace of the third, and the iron will and power of the last. Equally so the power of the Church and the warlike habits of the Middle Ages are unmistakeably impressed upon their architecture. What character will the buildings of the present age hand down to those that come after us? One stamp will undoubtedly be that of utility. The great majority of modern buildings of any importance are for the many rather than the few. Our railways, churches, markets, exchanges, town-halls, libraries, baths, are for the people at large. Another character is that of comfort. The standard of life is higher than at any former period, and all classes require attention to details which would have been utterly ignored a century ago. With regard to mansions of any pretence, it may be added that another characteristic is that of luxury. By this I mean something beyond either comfort or amenity,—billiard-rooms, conservatories, marble halls, polychromic decoration, &c. I see nothing to condemn in this. It stimulates invention and design, and taxes the genius of our architects to the utmost.

At the opposite end of the scale the provision for healthy and commodious dwellings for the working class, at a rent within their means, becomes an increasingly difficult problem year by year, from the additional cost of land, labor, and materials. Efforts are constantly being made in this direction with a certain degree of success, and the impulse thus given must ultimately lead to a solution of the problem.

Architecture is history in stone and brick; and you, gentlemen, in your ordinary occupation are constantly engaged in writing that history. It ought to be a noble one based on truth and honesty, and aspiring after the useful, the beautiful, and the good. In aiming at these ends personal aggrandisement may not always be the reward. The race is not always to the swift, nor the battle to the strong, nor, I may add, do the prizes uniformly fall to the lot of unpatronized merit; but I have great faith in perseverance and determination; and even if fortune should not ultimately crown your efforts, you will have had the satisfaction of adding to the conveniences and comforts of life, of producing some thing of beauty which may be a joy for ever.

Who would not rather be a Sir Christopher Wren, with all his vexatious disappointments and the base ingratitude with which he was treated, than have been the richest millionaire who ever lived.

Let the ideal of your art and calling be a high one,—too high to stoop to shifts, meannesses, or jealousies; sympathise with each other in your difficulties and trials; lend a helping hand to a brother in distress; be always ready to encourage the young seeking for advice and information; hold out the right hand of fellowship to all who are travelling in the same path, and in so doing you will find that union constitutes strength, you will magnify your office, and help to raise your profession to its right position, inferior to none of those which minister to the highest needs of mankind.

NOTES ON THE MASONRY OF THE EAST RIVER BRIDGE.

By FRANCIS COLLINGWOOD, C.E.

Abstract from Transactions of American Society of Civil Engineers.

Having spent considerable time during the past winter in getting together the details of the masonry and attachments of the East River bridge, so far as completed, and in revising the estimates of the work so far as practicable, the writer desires to place on record the following details respecting the two towers and anchorages.

The figures referring to the towers will be given chiefly in connection with the Brooklyn tower and important differences only will be noted. The principal dimensions of these structures are as follows:

HEIGHTS.

Brooklyn Tower :

	ft.	in.
Bottom of foundation below mean high tide	44	6
Base of stone masonry	20	0
Depth of water in immediate front of tower......12 to	16	0
Height of roadway above mean high tide	119	3
Height of springing of arches above high tide	198	0
Height of springing of arches above roadway	79	3
Height of ridge of roof stone above mean high tide	271	6
Height of ridge of roof stone above bottom of foundation	316	0

New York Tower :

	ft.	in.
Bottom of foundation below mean high tide	78	0
Bottom of stone masonry below mean high tide	46	6
Depth of water at immediate front of tower	34	0
Bottom of foundation to ridge of roof	349	6

In addition to all, there will be a balustrade around the towers on the cornice at the roadway and also at the edge of the roof slopes. This will increase the height to 276 feet above tide.

AREAS, OR HORIZONTAL SECTIONS.

	feet.	sq. ft.
At bottom of foundation (that is—bottom edge of caisson) :		
Brooklyn tower is	102×168	=17,136
New York tower is	102×172	=17,544
At top of timber, the extreme measurements of the base of the masonry are : for		
Brooklyn tower, 151×49 ft. with a solid section.		= 8,542
New York tower, 77×157 ft. with a solid section.		= 9,115
At high water surface, the extreme measurements are :		
Brooklyn tower, 57×141 ft. with a solid section.		= 5,172
New York tower, 59×141 ft. with a solid section.		= 5,968
First 10 feet above high water of		
Brooklyn tower, 56×140 ft. with a solid section.		= 4,983
New York tower, 59×140 ft. with a solid section.		= 5,172
Brooklyn tower about 39 ft. between 1st and 2d sloping offsets	$53\frac{1}{2}\times137\frac{1}{2}$	= 4,605

	feet.	sq. ft.
Brooklyn tower about 38 ft. of same between 2d offset and cornice......	51 × 135 =	4,100
Brooklyn tower, about upper member of cornice at roadway............	=	4,932
At the base of the three shafts above the roadway, extreme measurements of Brooklyn tower, 45 × 131 ft. solid section of same (united)...........	=	2,297
At the springing of the arches, extreme measurements of same, 42½ × 128½, solid section (united)........... ..	=	1,952
At base of upper cornice, extreme measurements of same, 40 × 126 feet, with solid section	=	2,940
Top members of upper cornice, extreme measurements, 49 ft. 10½ in. × 135 ft. 10½ in., with a solid section	=	4,343

Above high water, the New York tower differs from the other only by an increase of 3 feet of thickness in the direction of the axis of the bridge.

QUANTITIES OF MASONRY.

BROOKLYN TOWER:

	cub. yds.
From base of masonry to 2 feet 4 inches above tide..................	6,144
From 2 ft. 4 in. above tide to roadway	19,250
From roadway to springing.........	6,033
From springing to top of tower.....	6,787
Total stone work, excluding balustrades.............................	38,214
Concrete in well holes, caisson chambers, on top of timbers, and between timbers............................	5,669
Timber and iron in Brooklyn caisson	5,253
Total cubical contents........	49,136

NEW YORK TOWER:

	cub. yds.
From base of masonry, to 3 feet 7 inches above tide...................	13,383
From thence to roadway............	19,820
From roadway to springing..........	6,329
From springing to top of tower......	7,413
Total masonry, excluding balustrade	46,945

The timber and concrete in the New York tower are about one-third more in quantity than in the Brooklyn tower. The amount has not* been made up.

WEIGHTS.—Taking, per cubic foot, the granite masonry at 153 pounds, the concrete at 120 pounds, and the timber with contained iron and concrete, at 70 pounds, we get:

BROOKLYN TOWER:

	net tons.
Total weight of stone masonry......	78,931
Total weight of concrete............	9,184
Total weight of timber*, &c.........	4,964
Total................	93,079

* September 1st, 1876.

PRESSURES.—From the foregoing we get, for the Brooklyn tower:

	Tons per sq. ft.
Pressure at bottom of foundation, about..	5½
Pressure at base of masonry (per square foot of bed) about.....................	9¼
Pressure at high tide (per square foot of bed).................................	13
Pressure at base of central shaft above roadway, final (pressure), about........	26

The latter is the greatest pressure at any point in the tower masonry, being but 361 pounds per square inch, and it includes the pressure resulting from the two central cables. At the bottom of the foundation of the New York tower, the pressure is about 6¾ tons per square foot of area, and at the base of the masonry, about 10½ tons per square foot of bed. The pressures at the bases of the masonry will be increased about 8 per cent. by the weight of the superstructure and load.

The general form of the tower masonry is shown in plan by the following. (Fig. 1.) It consists of three buttressed shafts, joined together so far as the roadway, by four connecting walls. At the course next the timber in the Brooklyn tower, these walls are 17 feet thick; this thickness diminishes by offsets, until at high water and above, it is 10½ feet only.

Below high-water, the two well holes thus formed are filled with concrete and from high-water to the roadway, they are left open. Water, in considerable quantities, collected in them during construction.

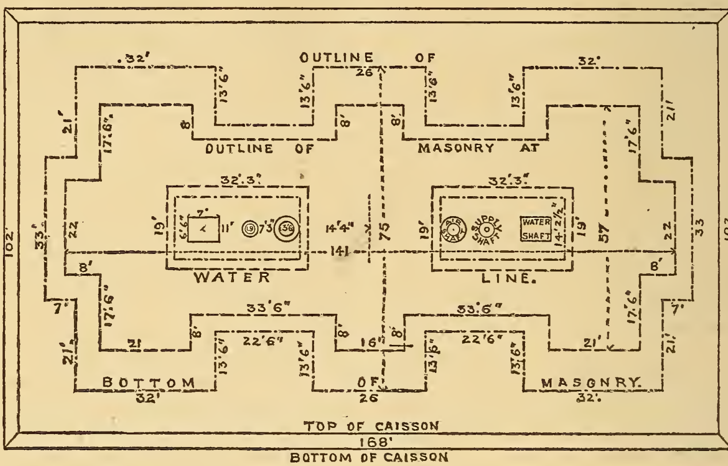
Similar well holes or spaces were left from 2 feet above the arches to within 4½ feet of the top of the tower, but each of them is divided by an interior connecting wall (paralled to the others), thus making four spaces of 4 × 33 feet section and 25 feet high.

The only other space in the masonry is a small vertical opening in one of the side shafts, 2 feet 5 inches × 3 feet, starting just above the springing of the arch and connecting with one of the well holes above. By means of an iron ladder in these openings, and a trap through the roof courses, permanent access can be had to the roof.

Each arch has a span of 33 feet 9 inches. The arches are pointed and formed by the intersection of two arcs of circles described from centers in the springing plane, with radii of 45 feet 9¼ inches. The extrados has a radius of 48 feet 2 inches, with centers in the springing plane, so placed as to give a thickness of arch of 5 feet at the springing and of 4 feet at the point. The points of the arches are 114 feet 4 inches above the roadway.

The changes which have been noted in the dimensions of the horizontal sections are made by sloping offsets in the buttresses, each of 7 feet 6 inches rise. Two of these are below and two above the roadway, and they connect the several vertical sections mentioned.

Fig. 1.



Leaving the subject of dimensions, the next thing in order is the character of the masonry. Throughout the work the specifications for stone have required, among other conditions, that the beds of all stones should be rough axed (or pointed), so as to allow of ½ inch bed joints, with no pitch holes of more than 9 inches diameter, or 1½ inches depth; and that the stone should be cut true to the rise. All vertical face joints from 4 feet below tide are ½ inch; below this, only good quarry faces were required; this gave joints of 4 to 12 inches, and closer ones could be secured for the face, by selecting the stone. In dimension backing, the vertical joints were to be from 1 to 3 inches in width, and in all common backing, quarry faces were allowed.

Except where a face stone abutted against dimension backing, the rear face was left rough. Headers were allowed to be wilder at the rear than the face, provided they were jointed back sufficiently for the adjacent stretchers. All face stone were paid for, according to the dimensions on the plan, deficiencies on each stone being charged for at contract price, and excess allowed for as backing. The rule was finally adopted and is now a part of every specification, that all stones of irregular shape (such as arch stones, cornice stones, &c.) shall be paid for, according to strict net measurement of their cubical contents; no constructive measurement being allowed. All bidders were notified to make their bids on this basis. The rises of the courses have been fixed in every case—the contractor bidding on specific rises. To accommodate the quarries, however, this has been varied between the limits of 20 and 30 inches; few being less than 27 inches, and the greater number being of 24 inches rise. The lengths of stretchers were fixed at from 6 to 15 feet, according to position, and the widths at from 3 to 5 feet. For ordinary stretchers, the contractor was allowed to vary in width within moderate limits, where it did not affect stability or plan.

Headers were made from 3 to 6 feet in width, the most common being from 3 to 4 feet, and none were allowed less than 6 feet long. The face stones ranged in cubical contents from 1½ to 5 cubic yards each (the face key-stones measuring 5½ yards each). The backing will average 1¼ cubic yards per piece in limestone, and $1\frac{1}{2}$ cubic yards in granite. All but the cornice and offset stones, from high water to the roadway, have a rock face of about 4 inches projection, and the arrises are pitched to a line. The corners of the buttresses have a vertical chisel draft of $1\frac{1}{2}$ inches width. The arrises of all the offset stones have the same draft, and the face between is pointed down to a $\frac{1}{2}$ inch projection. To heighten the contrast and produce the effect of horizontal bands, the granite in the offsets is of much lighter color than the rest of the stone. The faces of all the cornice stones are of six cut work (except on the sloping offsets as before described). Above the roadway, the face stones of the buttresses have the rock face projection reduced to about 3 inches; and a chisel draft is carried around the face of every stone. The pilasters facing the roadways are finished like the offset stones; and the intrados of the arches are smooth-pointed. The outer arch stones have a draft 3 inches wide, cut on the curved edge of the face and 2 inches wide on the other face edges; thus making a raised panel of $1\frac{1}{2}$ inches height, which is rough pointed between the drafts.

The voussoirs have a uniform thickness (length of curve on intrados) of 2 feet 3 inches. This gives a constantly diminishing thickness of the spandrel courses. The buttress and spandrel courses were, however, made to correspond in rise to the top of the thirteenth arch course (this having a rise on the spandrel of $23\frac{3}{4}$ inches). The eighteenth spandrel course had a rise of only $18\frac{1}{4}$ inches, and from the thirteenth to the eighteenth, the spandrel and buttress courses were unconformable. The bond was obtained by cutting down each and interlocking at the intersections, as best served to secure strong work. The study for this purpose was done by means of a model. The reason for not using thinner buttress courses and thus avoiding the necessity for such a construction, was, that the courses were too thin for the sizes of stone, required by the regular bond in the buttresses.

The general rule of the bond throughout the work, is two stretchers to one header.

The masonry of the towers below water is mostly of limestone, except the facing of the upper two courses, which is of granite. The backing above high water and below the roadway is mostly granite, all the remainder of the work being granite.

The anchorages were built entirely of limestone, with the exception of the corners, the front arches and the cornice. There were also about 650 cubic yards of heavy granite blocks in each anchorage, placed immediately over the anchor-plates, in order to secure a good hold upon the masonry above.

The limestone used has come from Kingston, Essex, Willsboro Point and Isle de La Motte, on Lake Champlain, and a small quantity from Canajoharie—all in New York. The granite of the towers has come from Deer Island, Fox Island, Mount Desert, Blue Hill, Frankfort, Spruce Head, Green's Landing and Cape Ann—all in Maine; that for the anchorages came from Stony Creek, Conn.; Westerly, Rhode Island; Frankfort, Maine, and Charlotteburg, New Jersey.

The gravel used in concrete was beach gravel from various points on the north shore of Long Island. It contained a little sand, but was entirely free from dirt. The sand at first used was from Red Bank, off Staten Island; but the excavation for the Brooklyn anchorage furnished an abundant supply for all subsequent work. The cement used has been of the various brands known as Rosendale, no lime having been used at any time. This being a slow setting cement, there is a great advantage in using it where heavy blocks of stone are to be set and adjusted.

The ordinary proportions of sand, &c., used, have been by bulk—for mortar, one part cement and two sand; for concrete, one part cement, two parts sand, and four parts gravel; around the anchor bars and at some other points, the proportions were, one, two, and three. No grouting has been permitted, except in rare cases where no other method was practicable; the general rule being, that all joints must be wide enough, at least for mortar; free use being made of "swords" and rammers, so as to insure perfect filling of joints.

In making up joints in the backing (wherever the spaces were wide enough to admit them,) broken stones of irregular sizes from a cubic foot down, were rammed into the concrete, until the spaces would receive no more. Great care was always taken to keep the work clean and to wet the faces of the stone. The face joints were dug out to a depth of 1½ inches and pointed with pure cement mortar; a bead finish of about ¼ inch projection being put on with a tool. The pointing has never cracked, except when done too late in the season, or when the mortar was allowed to take its first set before using; re-tempered mortar is sure to crack.

In this connection it may seem proper to state that whenever necessary, the work has been carried on in freezing weather, and no bad results have been observed. The tops of the various pieces of work were always gone over carefully in the spring. The concrete which had been put in late would usually be found disintegrated to a depth of 1 to 4 inches; but below this it always was perfectly sound. The rule seemed to be that it was unsound only so far as it was exposed alternately to freezing and thawing, and whenever it had taken a set before freezing, and not been thawed out for some time, it was sound.

The total quantity of joints, both vertical and horizontal, for all the work done up to fall of 1875 was as follows:

	cub. yds.
Total masonry laid	120,235
Total stone used in masony.......	100,015
Excess of masonry over stone.....	20,220
Excess of masonry in per centage of amount laid................	16.8

The excess is made up of mortar, concrete and broken stone; it is probable that the per centage is about 20 for the anchorages, and 15 for the towers; but the figures may be modified by the work of the past summer.

Before construction, a careful analysis was made of the thrust, line of pressure, &c., in the arches under the various conditions of load to which they would be subjected. This showed that the center line of pressures, resulting from the pier only, intersected the bases of the outer shafts at the roadway, at about one-third of their thickness from the outer faces; and that with the bridge completed, the intersection at this plane was close to the vertical lines through the center of gravity of the shafts.

The deflection of the center span of the cables is about 128 feet, and of the land spans about 187 feet, and the resultant of pressures from the cables falls in each pier slightly towards the river side of the center line.

To provide against possible changes of form, or accident during construction of the arches, the following precautions were taken:

At the top of the third voussoirs, four heavy irons were anchored into the masonry on each side of each arch, to which 3 inch-round iron rods spanning the arches were attached. Each rod was provided with a turn-buckle for tightening. Aside from serving to stiffen the arches, these rods served a very convenient purpose, as supports for scaffolds, while removing the centers and pointing the joints.

Permanent strengthening bars were inserted in both the first and second courses over the arches; there being in all 6 bars, 5×1¼ inches, over each arch, anchored well into the shafts on either side.

Experience has shown the necessity of another precaution to obviate the evil effects of the unequal distribution of pressure over the base of the masonry. By simple inspection it will be seen that the pressure per square foot at the base of the connecting walls is less than half of that at the base of the shafts. Hence there would be a tendency towards less compression and settlement under the connecting walls, and a consequent bulging upward at the roadway, causing vertical cracks in the connecting walls. This actually occurred to a limited extent in the Cincinnati bridge. To obviate this tendency, bars were inserted in top of the fourth, fifth and sixth courses below the roadway, in all 16 bars, 5×1¼ inches, long enough to anchor into the shafts. In addition, the stones of the connecting wall for several courses were clamped together by 1½ inch-round iron clamps.

Three sets of 2×10 inch-steel bars were inserted at each side of the pier, at the roadway, to serve as attachments for the under floor storm cables.

A set of flat iron bars were inserted at 20 feet below the roadway, as attaching points for holding down stays.

20 bars, 5 × 1½ inches, reaching en-

tirely across the tower, were inserted in the top of the second course below the saddle plates; and in the course below this, 16 other bars, 5 × 1¼ inches. The ends of these bars serve as attaching points for a portion of the long stays to the river and land spans of the roadway.

Small irons were inserted at frequent intervals to serve as attaching points for scaffolding, stairway, &c.

On each pier, on specially prepared beds, 4 saddle plates, each 8 × 16 feet, and weighing 11 tons each.

All irons were thoroughly galvanized before insertion. The saddles and plates were thoroughly coated with boiled linseed oil.

History.—The contract for the Brooklyn caisson was let October 25th, 1869, and work upon it began soon afterward. With the exception of surveys and office work, this was the first work done upon the bridge.

The Brooklyn caisson was launched March 19th, put in place May 2d, and the first stone set, June 15th, 1870; the interim between launching and stone setting being occupied, by putting on ten courses of timber, and various preparatory work. Work on the masonry stopped at an ultimate height of 6 inches above tide, December 10th, 1870. By March 11th, 1871, the chambers of the caisson were filled with concrete, being at the average rate of about 50 yards per day.

It is worth while to note here that the balance of pressure against the caisson while lowering, was decidedly towards the river; and this resulted in a movement outward of the whole mass, of nearly 2 feet, during the descent. As this had been anticipated, and the base of the masonry made abundantly large, the position was readily corrected at the high-water surface.

The total time occupied from the time of letting the first contract was five years and seven months. Reckoning from the bottom of foundation, therefore, the average height built per year, was 57 feet. This progress would have been considerably more rapid, had there been no delays from causes beyond the control of the engineering department.

The contract for the New York caisson was let September 6th, 1870; and it was launched May 8th, following. September 11th, 1871, it was put in place; the 17 extra courses of timber (and concrete spaces) were completed between time of launching and October 31st, on which day the first stone was laid.

Stone laying, with the exception of a few very cold days, was continued all winter. This was necessary, in order to give sufficient weight to sink the caisson as the excavation proceeded. May 17th, 1872, the caisson reached its final resting place, and filling in began; the masonry being at this date about 2 feet above tide. The chambers were all filled by July 22d. Although this time is shorter than that occupied in Brooklyn, the spaces to be filled were proportionally less. The masonry was stopped December 7th, 1872, at 60 feet above tide; begun again April 1st, 1873, and stopped November 22d, at 6 feet above roadway, or 126 feet above tide; begun again June 22d, 1874, and stopped December 12th, at 200 feet above tide; begun again April 29th, 1875, and stopped November 27th, at 243 feet above tide; begun again April 10th, 1876, and was finished, so far as possible, until after cable making, by the middle of July, or altogether in about five years and ten months.

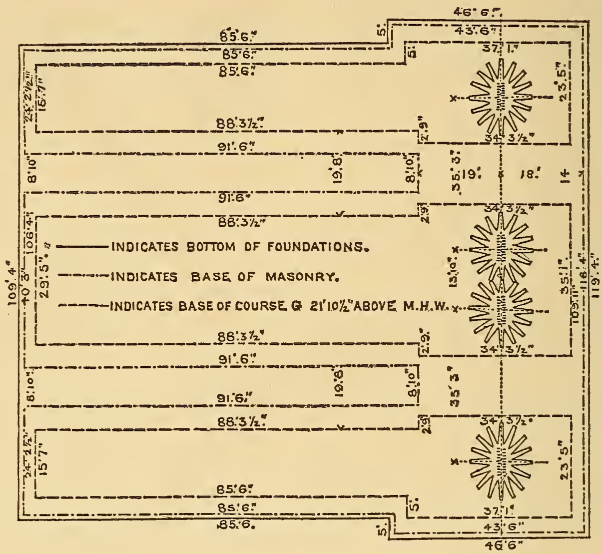
Delays have attended this structure the same as the other. The final results show, that under all ordinary circumstances, about five years must be allowed for the erection of such a structure.

Anchorages.—These rest on timber foundations, with the spaces between sticks, 2 to 5 inches, and filled with concrete. The extreme dimensions of the Brooklyn anchorage foundation are, 119 feet 4 inches by 132 feet. It is 4 feet deep, its base reaching to tide level, and the whole being constantly wet by water in the sand. The excavation was from 20 to 25 feet deep, and the foundation rests on a uniform bottom of fine sand.

The New York anchorage has a similar foundation, 119 feet 4 inches wide, but extending at the front so as to be 138 feet long. This change was made on account of the character of the bottom across the front edge. The ground here had been filled in, and the excavation was continued until a uniform bottom of clean sand and gravel was reached over the whole surface. The foundation is all below tide, and has a depth of 4 to 7 feet.

The masonry of the Brooklyn anchorage, therefore, starts at 4 feet above tide, and that in New York at high tide level. The anchor plates in Brooklyn have their upper surface at 8 feet, and in New York, at 6 feet above tide. The general plan for the anchorages is here shown.

Fig. 2.



The walls, both outside and in the main tunnels, have a batter of ½ inch per foot rise. The exterior measurements of the cornice are 124 feet, by 111 feet 8 inches at rear, and 101 feet 8 inches at front. The main tunnels are arched over by semicircular arches of 23 feet span, springing at 62 to 66 feet above tide. The rear tunnels have vertical walls, and are arched by semicircular arches of 14 feet span. These were not a part of the original plan, but were inserted to give means of communication from front to rear.

For 29 feet above tide in Brooklyn, and 22 feet in New York, the stones, except over the anchor plates, are all limestone, with rock face pitched to a line on the arrises. At these heights there is a 10 inch offset carried around all the faces except those of the rear tunnels, and above this the corner stones at each exterior angle are of granite. The corner stones have a bold chamfer, 4 inches broad, cut entirely around each face, except at the projecting corner. The faces between the chamfers have a draft 1½ inches wide cut around each, and the surfaces between, pointed to ½ inch projection. The limestone has the same finish throughout, as at first described. The cornices are of granite, corresponding in detail to those of the towers.

The New York anchorage contains 28,803, and the Brooklyn anchorage 27,113 cubic yards of masonry.

The anchor bars start from each plate in double sets, one curving over the other. They are vertical for about 25 feet, and then curve about 90°, so that the radius of a circle through the lower pins is 49 feet 6 inches. From this point, they extend to within 25 feet from the front edge of the masonry, where the cables are attached. The links of the first three sets have a section, 7×3 inches; the next three, 8×3 inches, and the next three, 9×3 inches. The tenth set is double in number, and each, $1\frac{1}{2} \times 9$ inches. The total weight in each anchorage is about 1,000,000 pounds. At each knuckle of the chains a large piece of granite is set, with a heavy cast iron plate inserted, as a bearing for the heads of the links.

Aside from these bars, there are heavy bars inserted for attaching the cradle and foot-bridge cables, for attaching the wind guys, and minor irons for temporary work.

The work of excavating for the Brooklyn anchorage began February 15th, 1873. The foundation was completed, and the first stone laid, June 26th. Work stopped November 29th, at 27 feet above tide. The approximate cost of the season's work, for 8,334 cubic yards of masonry laid, was $18 per cubic yard, of which $13.34 was for stone.

Work began again June 11th, 1874, and continued until December 29th, reaching 61 feet above tide; it was again resumed April 6th, 1875, and was completed as far as practicable till after cable making, October 1st, 1875, a total of 24,132 cubic yards having been laid.

Work on the New York anchorage began about May 1st, 1875, and the first stone was set August 5th; work was closed December 11th, 15,067 cubic yards of masonry having been laid during the season, at an approximate cost of $14.50 per yard; of which $9.50 were for stone; work began again April 10th, 1876, and the masonry was completed ready for cable making August 31st.

Estimates have not been made up, for this season's work. The increased cost in New York for labor, etc., is due to the greater delays in handling material and to pressing the work, two gangs of masons being employed during the day and one at night, instead of one day gang.

Approximate estimates of the cost of the Brooklyn tower, as it stands, show that the masonry for labor and contingencies (or everything but materials used in masonry), cost per cubic yard, $7.84. This includes labor, foremen, machinists, watchmen, scaffolding, wear and tear, rent of stone yard, towing scows, coal, &c., and may be subdivided as follows:

Top of caisson to high tide, per cubic yard	$4.96
High tide to roadway, about per cubic yard	6.36
Roadway to springing, about per cubic yard	9.70
Springing to top, about per cubic yard.	12.60

Of this, the cost on the stone from the time it was laid alongside the dock, at Red Hook, until it was laid alongside at the pier, averaged $1.10 per yard. If we deduct this, from the cost of each portion as previously given, we get the relative costs (independent of cost of stone) of the various portions about as the following numbers:

Below tide	13
Tide to roadway	18
Roadway to springing	29
Springing to top	39

In other words, the first eighty feet above the roadway cost about one and one-half times as much per yard for labor and contingencies as the 120 feet from high tide to roadway, and the seventy-two feet above springing about twice as much.

The average cost of the stone used in the Brooklyn tower, delivered at Red Hook, was about $21 per cubic yard, varying all the way from $15 to $83 per cubic yard.

Excavation in the Brooklyn caisson, cost for labor only, including the men on top, about $5.25 per cubic yard. Running the six air compressors added to this, $3.60 per hour, or about 47 cents per yard; lights added, $0.56 more; and these with other contingencies nearly equalled the cost of labor. The great cost was due to the excessive hardness of the material over much of the surface; the caisson finally resting over nearly its whole extent on a mass of boulders, or hard pan.

The concrete in the caisson cost about $15.50 per cubic yard for every expense. The caisson and filling together aggregated 16,898 cubic yards; and the approximate cost per yard for every expense was $20.71. This was less than the cost of masonry laid in the open air.

The labor of making these estimates is very great; and it has not been done for the New York tower.

Bringing the account of the work up to the latest date, it is sufficient to say, in closing, that the settlement of the Brooklyn tower, at the time of completing the masonry (measured from marks at all salient angles, which were made immediately after the work reached high water), averaged 0.101 feet, the extremes being 0.08 and 0.102 feet. The average for the New York tower was $1\frac{1}{8}$ inches, with a still closer correspondence, but the figures are not at hand.

The settlement of the New York anchorage from the time of reaching twenty-two feet above tide, when the levels of all salient angles were referred to a permanent bench mark, was ¾ inch across the front, and 1¾ inches across the rear. The difference is no doubt due to the greater proportional weight at the rear. The figures for the Brooklyn anchorage are about the same, but are not at hand.

FUEL.*

By Dr. C. W. SIEMENS, F.R.S.

From "The Engineer."

Next in importance to cheap, or rather to efficacious labor, in the production of iron and steel, comes cheap fuel—a subject to which, as you are aware, I have devoted considerable attention, and I would, therefore, treat it, with your permission, rather more fully than other subjects of perhaps equal importance. Fuel, in the widest acceptation of the word, may be said to comprise all potential force which we may call into requisition for effecting our purposes of heating and working the materials with which we have to deal, although in a more restricted sense it comprises only those carbonaceous matters which, in their combustion, yield the heat necessary for working our furnaces, and for raising steam in our boilers. It may safely be asserted that the great supply of energy available for our purposes has been, or is being, derived from that great orb which vivifies all nature—the sun. In the case of coal, it has been shown that its existence is attributable to the rays of the sun, which in former ages broke up or dissociated carbonic acid and water in the leaves of plants, and rendered the carbon and hydrogen, thus separated from the oxygen, available for re-combustion. The same action still continues in the formation of wood, peat, and, indeed, all vegetable matter. The solar ray produces, however, other forms of energy through the evaporation of sea-water, and the resulting rainfall upon elevated lands, and through currents set up in the atmosphere and in the sea, which give rise to available sources of power of vast aggregate amount, and which may also be regarded in the light of fuel in the wider sense. The form of fuel which possesses the greatest interest for us—the iron smelters of Great Britain of the nineteenth century, is without doubt the accumulation of the solar energy of former ages, which is embodied in the form of coal, and it behoves us to inquire what are the stores of this most convenient form of fuel. Recent inquiry into the distribution of coal in this and other countries has proved that the stores of these invaluable deposits are greater than had at one time been supposed. I have compiled a table of the coal areas and production of the globe, the figures in which are collected from various sources. It is far from being complete, but will serve us for purposes of comparison :

THE COAL AREAS AND ANNUAL COAL PRODUCTION OF THE GLOBE.

	Area in square miles.		Production in 1874. Tons.
Great Britain....	11,900	..	125,070,000
Germany	1,800	..	46,658,000
United States...	192,000	..	50,000,000
France	1,800	..	17,060,000
Belgium	900	..	14,670,000
Austria.........	1,800	..	12,280,000
Russia..........	11,000	..	1,392,000
Nova Scotia....	18,000	..	1,052,000
Spain	3,000	..	580,000
Other countries.	28,000	..	5,000,000
	270,200	..	274,262,000

This table shows that, roughly, the total area of the discovered coal-fields of the world amounts to 270,000 square miles. It also appears that the total coal deposits of Great Britain compare favorably with those of other European countries; but that both in the United States and in British North America, there exist deposits of extraordinary magnitude, which seems to promise a great future for the New World. According to the report of the Coal Commissioners, published in 1871, there were then 90,207 million tons of coal available in Great Britain, at depths not greater than 4000

* Abstract of Inaugural Address of Dr. Siemens before the Iron and Steel Institute.

ft., and in seams not less than 1 ft. thick, besides a quantity of concealed coal estimated at 56,273 millions of tons, making a total of 146,480 millions. Since that period there have been raised 600 millions of tons up to the close of 1875, leaving 145,880 millions of tons, which at the present rate of consumption of nearly 132 millions of tons annually, would last 1100 years. Statistics show that during the last twenty years there has been a mean annual increase in output of about 3½ millions of tons, and a calculation made at this rate of increase would give 250 years as the life of our coal-fields. In comparing, however, the above rate of increase with that of population and manufactures, it will be found that the additional coal consumption has not nearly kept pace with the increased demand for the effects of heat, the difference being ascribable to the introduction of economical processes in the application of fuel. In the case of the production of power, the economy effected within the last twenty years exceeds 50 per cent., and a still greater saving has probably been realized in the production of iron and steel within the same period, as may be gathered from the fact that a ton of steel rails can now be produced from the ore with an expenditure not exceeding 50 cwt., of raw coal, whereas a ton of iron rails, twenty years ago, involved an expenditure exceeding 100 cwt. According to Dr. Percy, one large works consumed, in 1859, from five to six tons of coal per ton of rails. Statistics are unfortunately wanting to guide us respecting these important questions. Considering the large margin for further improvement regarding almost every application of fuel which can be shown upon theoretical grounds to exist, it seems not unreasonable to conclude that the ratio of increase of population and of output of manufactured goods will be nearly balanced, for many years to come, by the further introduction of economical processes, and that our annual production of coal will remain substantially the same within that period, which, under those circumstances, will probably be a period of comparatively cheap coal. The above-mentioned speculation leads to the further conclusion that our coal supply at a workable depth will last for a period far exceeding the shorter estimated period of 250 years, especially if we take into account the probability of fresh discoveries, of which we have had recent instances, particularly in North Staffordshire, where a large area of coal and blackband ironstone is being opened up, under the auspices of his Grace the Duke of Sutherland, by our member, Mr. Homer. Wherever coal-fields are found in Great Britain, they exist, generally speaking, under favorable circumstances. The deposits are for the most part met with at reasonable depths, the quality of the coal is unsurpassed by that of other countries, and although the coal and ironstone do not occur together in all the iron-producing districts, the distance from the coal to the iron is small, compared with that met with in other countries, and the insular position of Great Britain renders water carriage, both for internal communication and for the purpose of export, more readily available than elsewhere. These advantages ought to decide the present contest for cheapness in supplying the markets of the world with iron and steel in favor of this country. Coal assumes, in many instances, the form of anthracite, and although the South Wales district contains large deposits of this mineral fuel, comparatively little use has been hitherto made of it for smelting purposes. When raw anthracite is used in the blast furnace mixed with coke, it has been found that the amount so used should be limited to from 10 to 15 per cent. or the furnace is apt to become choked by an accumulation of decrepitated anthracite. At Creusot, in France, this difficulty was overcome many years ago by crushing the anthracite coal, mixing it intimately with crushed binding coal, and coking the mixture of about equal proportions in Appold's vertical coke ovens. The result is a somewhat unsightly, but exceedingly hard and efficacious coke. A similar method has been followed for some time in South Wales, where coke is now produced, containing as much as 60 per cent. of anthracite, bound together by 35 per cent. of binding coal, and a further admixture of 5 per cent. of pitch or bitumen, the whole of the materials being broken up and intimately mixed in a Carr's disintegrator prior to being coked in the usual manner. Coke of this description possesses great power of endurance in the furnace, and is worthy the attention of iron smelters. In the United States of America, anthracite plays a most important part, being, in fact, the only mineral fuel in the Northern States east of the Alleghany mountains. Its universal application for blast furnaces, for heating purposes, and for domestic use, imparts to the eastern cities of the United States a peculiar air of brightness, owing to the entire absence of smoke, which must impress every visitor most agreeably, and the difference of effect produced by the general use of this fuel, as contrasted with that of bituminous coal, is most strikingly revealed in a short day's journey from Philadelphia, the capital of the anthracite region, to Pittsburgh, the center of application of bituminous coal. In visiting lately the deposits of anthracite coal of the Schuylkill district, I was much struck with their vastness, and with the manner and appliances adopted for working the same. The American anthracite is less decrepitating than ours, but its successful application to its various purposes is the result chiefly of the judicious manner in which it is prepared for the market. The raw anthracite as it comes from the mine is raised to the top of a wooden erection some 80 ft. or 90 ft. high, in descending through which it is subjected to a series of operations of crushing, washing, sieving, and separating of slaty admixtures, after which it is delivered through separate channels into railway wagons, as large coal, as egg coal, walnut coal, and pea coal, each kind being nicely rounded and uniform in size. The dust coal, which amounts to nearly one-half of the actual quantity raised, is allowed at present to accumulate near the mine, but experiments are now being carried out to utilize this also for steam-boiler purposes. Next in importance to mineral fuel, properly speaking, are lignite and peat, of which vast deposits are met with in most countries. These may be looked upon as coal still in course of formation, and the chief drawback to their use, as compared with that of real coal, consists in the large percentage of water which they contain, rendering them inapplicable in their crude condition to the attainment of high degrees of heat. These difficulties may be overcome by subjecting the wet material to processes of compression, desiccation, and coking, whereby excellent fuel and products of distillation have been obtained, although the cost of their production has hitherto exceeded their market value. Crude air-dried peat has, however, been rendered applicable for obtaining high degrees of heat such as are required for metallurgical operations by means of the regenerative gas furnace; and it is important to observe that the calorific value of a ton of air-dried peat or lignite, if used in this manner, is equal to that of a ton of good coal if deduction is made in both cases of the percentage of moisture and earthy matter. The carbonaceous constituents of peat yield, indeed, a very rich gas suitable for melting steel or for re-heating iron, and the only precaution necessary is to pass the gas from the producer over a sufficient amount of cooling surface to condense the aqueous vapor it contains, before its arrival at the furnace. This precaution is not necessary, however, in dealing with some of the older lignites, such as occur abundantly in Austria and Hungary, and which may be ranked as almost equal in value with real coal, except for blast furnace purposes. Fuel also occurs naturally in the gaseous condition, a fact but too well known to every practical coal miner. Occasionally, however, it is found separated from the coal with which it may have been primarily associated, and in those cases it has been made practically available as fuel. At Baku, on the Caspian Sea, natural gas has issued spontaneously from the ground for centuries past, and the column of perpetual fire thus produced has served the purpose of giving the Parsees a holy shrine at which to worship their deity. In the district of Pennsylvania, a more substantial application has been made of the gas issuing from many of the borings, in providing fuel for working pumping machinery and in lighting the district. The quantity of gas issuing from some of these wells may be judged from the fact that one of them, after discharging for three years as much gas as could escape into the atmosphere under a pressure estimated at not less than 200 lbs. on the square inch, has lately been connected by means of a 5 in. pipe with Pittsburg —a distance of eighteen miles—where seventy puddling and re-heating furnaces are worked entirely by the fuel so supplied. But even this result furnishes only an imperfect idea of the calorific power represented by this single issue of natural gas, inasmuch as the combustion is carried on in these furnaces on the most wasteful plan, the gas being mixed imperfectly with cold air, and converted to a large extent into dense masses of smoke. An analysis of this gas gives :

Hydrogen	13.50
Marsh gas	80.11
Ethylene	5.72
Carbonic acid	0.66

Although the use of natural gas is not likely to assume very large proportions owing to its rare occurrence, its application at Pittsburgh has forcibly reminded me of a project I had occasion to put forward a good many years ago, namely, to erect gas producers at the bottom of coal mines, and by the conversion of solid into gaseous fuel, to save entirely the labor of raising and carrying the latter to its destination. The gaseous fuel, in ascending from the bottom of the mine to the bank, would acquire in its ascent, owing to its temperature and low specific gravity, an onward pressure sufficient to propel it through pipes or culverts to a considerable distance, and it would be possible in this way to supply townships with heating gas, not only for use in factories, but, to a great extent, for domestic purposes also. In 1869, a company, in which I took a leading interest, was formed at Birmingham, under the sanction of the Town Council, to supply the town of Birmingham with heating gas at the rate of 6d. per 1,000 cubic feet, but their object was defeated by the existing gas companies, who opposed their bill in Parliament, upon the ground that it would interfere with vested interests. I am still satisfied, however, that such a plan could be carried out with great advantage to the public; and although I am no longer specifically interested in the matter, I would gladly lend my aid to those who might be willing to realize the same. Fuel also occurs naturally in the liquid state, and if mineral oils could be obtained in quantities at all comparable to those of solid fuel, liquid fuel would possess the advantages of great purity and high calorific value; but, considering its rare occurrence and comparatively high price even in the oil districts of Pennsylvania and Canada, its use, as a fuel for smelting purposes, need not be here considered. According to the general definition of fuel given above, we have to include the evaporative effect of the sun's rays, by which sea water is raised to elevated mountain levels, whence it descends towards the sea, and in so doing is capable of imparting motion to machinery. This form of fuel, which takes the place of the coal otherwise expended in raising steam, has been resorted to in all countries since the dawn of civilization, and it is owing to this circumstance that the industries of the world were formerly very much scattered over the valleys and gorges of mountainous districts, where the mountain stream gave motion to the saw mill or flour mill, to the trompe of the iron smelter, and to the helve of the iron and steel manufacturer. The introduction of the steam engine, towards the end of the last century, changed the industrial aspect of the world in causing manufactories to be massed together in great centers, and this tendency has been still further augmented in consequence of the construction of canals and railways, which enable us to bring together the raw material, and to disperse the manufactured product at a comparatively low cost. It is not unreasonable, however, to expect that a certain reaction in this process of centralisation will gradually take place, because, in consequence of ever-increasing competition, the advantage of utilising natural forces, which we could afford to neglect during a period of general prosperity, becomes again an essential element in determining the very lowest price at which our produce may be sent into the market. The advantage of utilising water-power applies, however, chiefly to continental countries, with large elevated plateaus, such as Sweden and the United States of North America, and it is interesting to contemplate the magnitude of power which is now for the most part lost, but which may be, sooner or later, called into requisition. Take the Falls of Niagara as a familiar example. The amount of water passing over this fall has been estimated at 100 millions of tons per hour, and its perpendicular descent may be taken at 150 feet, without counting the rapids, which represent a further fall of 150 feet, making a total of 300 feet between lake and lake. But the force represented by the principal fall alone amounts to 16,800,000 horse-power, an amount which, if it had to be produced by steam, would necessitate an expenditure of not less than 266,000,000 tons of coal per annum, taking the consumption of coal at four pounds per horse power per hour. In other words, all the coal raised throughout the world would barely suffice to produce the amount of power that continually runs to waste at this one great fall. It would not be difficult, indeed, to realise a large proportion of the power so wasted, by means of turbines and water-wheels erected on the shores of the deep river below the falls, supplying them from canals cut along the edges. But it would be impossible to utilise the power on the spot, the district being devoid of mineral wealth, or other natural inducements for the establishment of factories. In order practically to render available the force of falling water at this, and the thousands of other places under analogous conditions, we must devise a practical means of carrying the power to a distance. Sir William Armstrong has taught us how to carry and utilise water power at a distance, if conveyed through high-pressure mains, and at Schaffhausen, in Switzerland, as well as at some other places on the Continent, it is conveyed by means of quick-working steel ropes passing over large pulleys. By these means, power may be carried to a distance of one or two miles without difficulty. Time will probably reveal to us effectual means of carrying power to great distances, but I cannot refrain from alluding to one which is, in my opinion, worthy of consideration, namely, the electrical conductor. Suppose water-power to be employed to give motion to a dynamo-electrical machine, a very powerful electrical current is the result. This may be carried to a great distance, through a large metallic conductor, and there be made to impart motion to electro-magnetic engines to ignite the carbon points of electric lamps, or to effect the separation of metals from their combinations. A copper rod of three inches in diameter would be capable of transmitting 1,000 horse power a distance of, say, thirty miles, an amount sufficient to supply one quarter of a million candle-power, which would suffice to illuminate a moderately sized town. The use of electrical power has sometimes been suggested as a substitute for steam power; but it should be borne in mind that so long as the electric power depends upon a galvanic battery it must be much more costly than steam power, inasmuch as the combustible consumed in the battery is zinc, a substance necessarily much more expensive than coal. But this question assumes a totally different aspect if in the production of the electric current a natural force is used, which could not otherwise be rendered available. The force of the wind is another source of natural power, representing fuel according to the general definition above given, which, though large in its aggregate amount, is seldom used, owing to its proverbial uncertainty. On this account we may dismiss it from serious consideration until our stores of mineral wealth are well nigh exhausted, by which time our descendants may have discovered means of collecting, storing, and utilising such a power in a manner entirely beyond our present conceptions.

STRENGTH OF IRON AND STEEL CONSTRUCTIONS—WITH CALCULATION OF DIMENSIONS.* I.

Translated from the German of "Weyrauch."

UNTIL within a short time the dimensions in steel and iron constructions were determined in the following way: The maximum strain, B, to which a member of a structure could be subjected, was found, and then divided by the permissible strain on the surface unit

$$(1)\quad F = \frac{max.\ B}{b}$$

which gave the area in superficial units of the section required for the member.

* Strength and Calculations of Dimensions of Iron and Steel Constructions, with reference to the latest Experiments. By J. J. Weyrauch, Ph.D. Four folding plates. New York: D. Van Nostrand.

The same value was always given to b, both in case of static and live strains. In Prussia, for example, it was generally assumed that for iron, $b=730$ kil. per sq. cm.; and this served for tension, compression, and shearing.

Gerber made a new departure in the case of the Mayence bridge. A different b was taken for each member, varying inversely as the ratio of the strain due to total load to that due to weight of bridge.

Again, if a bar were subject to alternate tension and compression, the same formula was employed; *max.* B, indicating the greatest *absolute* value of B. The Americans were wiser, for they used the formula

$$F=\frac{max.\ B+max.\ B'}{b}$$

in which *max.* B' is the greatest strain in the sense opposite to that of B.

Numerous breakages of axles, boiler explosions, and failures of bridges, repeatedly called attention to the causes of these phenomena. Safety co-efficients were always introduced, which seemed to preclude all danger. Still the question, whether our iron bridges in general will live out their assigned terms, forced itself into notice. Experience can give no answer, for the use of iron in bridge-building dates back hardly a century. In 1874, the Union of German Architects and Engineers determined to seek a solution, by systematic observations. These observations are of the greatest importance; but, of course, no decisive result can be reached within a few years. Meanwhile, it is well to consider the results already obtained. To the question, whether the common method of determining dimensions will stand the test of unprejudiced criticism, we shall find a negative answer. This settled, and the method consigned to the limbo of past errors, we shall consider the best guides to further investigation, as suggested by the results of theory and practice brought down to date. "In order to see aright, one must know where to look," as Schelling says.

WOHLER'S LAW.

The experiments upon which the methods hitherto employed depended have been made during the course of a century by Perronet, Poleni, Telford, Brunel, and many others. Many of these experiments were very carefully made, and are not worthless; but they were all based upon a partial view. It was thought that a body once subjected to a certain strain, and withstanding it, must be able to endure the same strain, no matter how often repeated.

Proof was made by gradually increasing load of the single pull, pressure or shear, just sufficient to break a bar of square unit section; and the number, t, so obtained, was regarded as the corresponding strength of the material. This t is called the ultimate strength; and we know that any strain, whether constant or gradually increasing, but always less than t, will not rupture the material by a single application.

That violent and frequent shocks are especially unfavorable in their effects has always been known; but, in 1858, A. Wohler showed that besides this, as a basis of trustworthy calculation, experiments concerning resistance to often repeated strains must be made. Fairbairn immediately made trial of a riveted girder; first loading it with $\frac{1}{4}t$, then with $\frac{1}{3}t$. It stood 1,000,000 strains with $\frac{1}{4}t$, and broke with 313,000 more strains with $\frac{1}{3}t$. But general conclusions cannot be drawn from these results; for the apparatus was so contrived that the effects due to load, and those due to other disturbing causes, could not be distinguished.

In the years 1859 and 1870, Wohler made very exact and comprehensive experiments on iron and steel. The test-bars were made specially for the purpose, and all disturbing influences were eliminated. It was found, as was expected, that while a certain strain t, once applied may rupture the material, a less strain, often repeated, will induce rupture. Here was a new point of observation reached. It was obvious that the change in the grouping of molecules, caused by the changing strain, affected the resistance of the material unfavorably. Hence ease of rupture must be directly proportional to the increase of difference in strains; since there was a corresponding increase in the changes of positions of the molecules. Wohler was therefore able to state a general principle, which may be expressed as follows:

Rupture is caused not only by a dead load exceeding the ultimate strength, but also by often repeated strains, no one of which is as high as the ultimate strength. The differences of strains are therefore effective cause of destruction of cohesion in the degree that the minimum strain sufficient for rupture diminishes as these differences increase.

If the material is ruptured by the strain t once applied, strains less than t may cause breaking by repeated application; and the less the strain, the greater the number required for destruction, and conversely. Hence it is important in the determination of the degree of security to consider whether a structure is to remain in use for a limited time, as in the case of rails, axles, &c.; or is to stand for an indefinite period, as in the case of bridges, buildings, &c.

Wohler's experiments include tension, compression and torsion. Resistance to torsion is regarded as a kind of shearing resistance, and it is assumed that the shearing forces do not lie in a plane. Though the results of repeated compression were not found, it is to be inferred that they would be analogous with those obtained for tension. Not so, when compression and tension alternate. Here a single case was investigated, viz.: when the strains in both directions are equal; other cases are not yet filled out.

When Wohler left public office (1870), he asked the Prussian Minister of Trade and Commerce to have his experiments continued, and, upon the nomination of Reuleaux, Prof. Spangenberg was commissioned to the work. His experiments during a period of three years (Wohler's lasted twelve), are quite limited; but Wohler's law is fully confirmed by them. Spangenberg has given his attention to other metals; and, especially to the conditions of the surfaces of fracture under different kinds of strain; attempting to explain them by a hypothesis concerning the molecular constitution of metals. Further investigation in this direction would be of import to theory and practice, since there has hitherto been a total want of any general principles to determine judgment upon questions concerning the properties of resistance.

REMARKS UPON WOHLER'S LAW.

Wohler's law, as given above in general form, is doubtless correct; and it may be regarded as already established by experience, since we have often made unconscious use of it. If one wishes to break a rod with his hands, and a single effort is not sufficient, he lets it go, and gives another pull; and if this does not avail, he succeeds, perhaps, by bending it back and forth. The force of the arm is not greater in the last case; indeed, he does not need to use as much force. So it was known long ago that when there are repeated stresses in opposite directions, so that the differences of stress are the greatest, the force necessary for rupture is less than in case of stresses in a determined direction, or for a single stress.

It is surprising that for so long a time regard has not been given to the number and the kinds of strains that occur in the most important structures. Yet it is not to be forgotten that the methods of Gerber and the American engineers, mentioned above, were prompted by a correct feeling. Had more attention been given to them, it is possible that a course of experiments for years would not still be necessary to give a general but provisional expression to a law continually applied by every layman.

There is still room enough for the precise determination of Wohler's law in its theoretic and practical aspects. In his experiments the stresses followed one another in rapid succession; but they require a certain duration of time to attain their full intensity; unless the effect of shocks proper is under consideration. What effect have the rapidity of succession, the degree of increase, and the duration of stress? The influence of the two latter upon t is not yet determined.

It is not necessary to adopt Wohler's opinion that the different kinds of resisting strength of iron and steel can be obtained from one of the metals. It is enough to know that for stresses of determinate kind and determinate position of the plane of forces Wohler's law holds true.

Again, the general expression of the law and the results of experiment are to be considered separately. Of course, the figures fit exactly on those kinds of metal upon which Wohler made his experiments. But there has hitherto been no hesitation in ascribing to material employed a resisting strength determined upon other kinds of material, although, even within the range of fixed kinds, *e. g.*, rolled iron and plate iron, differences in resistance to single stationary load, amounting to 30, 40 and 50 per cent. are common. A little while ago, had any one ventured objection, the answer would have been, that there were co-efficients of safety. But these are still employed.

Though there are some effects to be determined and a very great number of data is desirable; still we have definitely, in Wohler's law, and provisionally in his tables, the best starting point for a rational determination of the dimensions of steel and iron members. The difference between the new and old methods is that while the former is of necessity not absolutely exact, the latter is in any event false.

LAUNHARDT'S FORMULA.

Suppose a rod of square-inch section strained but once by the ultimate load t; it will break. Make the stress a little less than t, then by Wohler's law, a certain number of repetitions are necessary to produce rupture. Let the stress decrease, then the number of repetitions required increases. A number must be reached at which the rod is safe as against any number of stresses to which it is actually subjected. Let the stress, for the case in which the rod returns to a perfectly strainless condition, be denoted by u; and let it receive the name given by Launhardt, original strength (Ursprungsfestigkeit). This is inversely as the number of stresses to be borne; so that for a rail which is to be changed for another in time, it is greater than for a member of a bridge which is to be permanent. We shall consider only the latter case, but the general formula will hold for all others; and u will vary between this value and the value t of ultimate strength. It follows from the definition that the difference of stress $d=u-0=u$.

Generally the rod does not return to a perfectly strainless condition, but there remains a minimum strain c. The stress, which in this more general case, causes fracture, Launhardt calls working resistance (Arbeitsfestigkeit), and indicates by a. The difference of stress is $d=a-c$, and $a=c+d$ (2).

By Wohler's law, a decreases as d increases. The limiting values of a are by (2), and the definitions of u and t

$$\text{for } c=o, \quad a=d=u,$$
$$\text{for } d=o, \quad a=c=t.$$

Ultimate strength and original strength are special cases of working strength. As a is a function of d we can assume

$$a=\alpha d \qquad (3)$$

in which α is an unknown quantity. But we know that

$$\text{for } d=o, \quad \text{since } a=t, \ \alpha=\infty,$$
$$\text{for } d=u, \quad \text{since } a=d, \ \alpha=1.$$

To these conditions corresponds the value chosen for α, by Launhardt.

$$\alpha=\frac{t-u}{t-a}$$

which remains to be tested for intermediate values by the results of experiments.

$$\text{From (2)} \qquad a=\frac{t-u}{t-a}d=\frac{t-u}{t-a}(a-c).$$

$$\therefore\ a=u\left(1+\frac{t-u}{u}\cdot\frac{c}{a}\right). \qquad (4)$$

Denoting by B, the stress upon a member,

$$\frac{c}{a}=\frac{\text{min. } B}{\text{max. } B},$$

$$\text{hence} \qquad a=u\left(1+\frac{t-u}{u}\cdot\frac{\text{min. } B}{\text{max. } B}\right) \qquad (I)$$

This is Launhardt's formula, and is applicable whenever a piece is always under the same kind of stress, whether of tension or compression. The value of u for compression is not yet determined, and the same values of t and u will be used both for tension and compression; this is justified by certain observations, and was used in respect to t in previous methods of calculation.

We shall, therefore, include the terms tensile, compressive, and shearing strength in one, and regard the working resistance as equivalent to the special stress under consideration.

It is yet to be determined whether Launhardt's choice of co-efficient α holds for intermediate conditions.

$$\text{From (4)} \quad a=\frac{u}{2}+\sqrt{\left(\frac{u}{2}\right)^2+c(t-u)},$$

the positive sign being taken, because a

is positive and greater than u. The value of t as well as of u may vary with the kind of stress and material; and α varies for a fixed value of c; hence all results should be obtained from experiments of the same kind, and with like material. The best results for comparison are, without doubt, those which Wohler obtained with Krupp's spring cast-steel not hardened; and Launhardt's formula receives confirmation from the fact that it corresponds exactly with these results. Wohler found for this steel, in bending tests $t=1{,}100$ centner, $u=500$ centner per square inch, hence the working resistance per square inch,

$$a=250+\sqrt{62500+600\,c.}$$

This equation gives the values in the third line below; Wohler's results appear in the second.

For c =	0	250	400	600	1,100
a, by experiment, =	500	700	800	900	1,100
a, by Launhardt, =	500	711	800	900	1,100

By former hypothesis, only the stress of 1,100 would have made rupture possible; while we see in the table that all stresses, down to 500, were sufficient to cause rupture.

FORMULAS FOR ALTERNATING TENSION AND COMPRESSION.

It often happens that the same member is subjected to alternate compression and tension. Since Launhardt's formula cannot be applied, another will be obtained by like reasoning, dependent upon Wohler's Law. Wohler has investigated the important case in which the stresses in both directions are the same, calling the resistance (s) vibration-resistance. If the strain in one direction is zero, then the resistance is denoted by u, the original resistance. Two limiting cases are given.

Let a rod of square-unit section be subject to alternate tension and compression. To each value of a of the greater of these stresses corresponds a certain value a' of the smaller in this respect; that for the greatest number of vibrations between $\pm\, a$ and $\mp\, a'$ the material remains sound. The difference in stress $d=a+a'$, therefore

$$a=d-a' \qquad (6)$$

According to Wohler's law, a varies inversely as d. Assume

$$a=\alpha\, d. \qquad (7)$$

But, for $a'=o$, $a=u=d$,
for $a'=s$, $a=s=\frac{1}{2}d$.

Hence from (7),

for $a=u$, $\alpha=1$,
for $a=s$, $\alpha=\frac{1}{2}$,

These conditions give the co-efficient

$$\alpha=\frac{u-s}{2\,u-s-a.}$$

Hence from (6)

$$a+\frac{u-s}{2\,u-s-a}\,d=\frac{u-s}{2\,u-s-a}\,(a+a')$$

and hence $$a=u\left(1-\frac{u-s}{u}\cdot\frac{a'}{a}\right) \qquad (8)$$

Now, if for a given member in a structure, max. B is the greatest stress exerted, whether of compression or tension, and max. B' the greatest in the opposite sense, we have,

$$\frac{a'}{a}=\frac{\text{max. } B'}{\text{max. } B}$$

$$\therefore\ a=u\left(1-\frac{u-s}{u}\cdot\frac{\text{max. } B'}{\text{max. } B}\right), \qquad \text{(II)}$$

and the value of a denotes the working strength.

The original resistance and the working resistance in the direction of the greatest absolute stress, max. B, are denoted by u and a. As u for compression is not yet known, the value for tension may be provisionally employed, being somewhat too small.

In some constructions the oscillations between a and a' begin with a stress equal to zero; in others, with a stress equal to c, mostly caused by the dead weight. The operation of a complete forward and back vibration must be the same, and cannot be essentially changed by the longer action of c, which lies far within the limits of elasticity.

Formulas (I) and (II) serve not only for stresses by tension and compression, but also for all other kinds, if the values of t, u and s are known.

If Φ denotes the ratio of the limiting stresses, the least to the greatest, on a member of a structure, our formulas read

For stress in a determined direction:

$$a=\left(1+\frac{t-u}{u}\Phi\right) \qquad (\text{I } a.)$$

For stress in the opposite direction,

$$a=u\left(1-\frac{u-s}{u}\Phi\right) \qquad (\text{II } a.)$$

ULTIMATE STRENGTH FOR TENSION AND COMPRESSION.

The old experiments with wrought-iron give more uniform and higher figures for ultimate strength than the later. Navier gives the results of seven experiments in France, England and Italy; the mean, per square centimeter, being 3,940, 4,220, 4,290, 4,450, 4,610, 4,680, 5,010 kil.

Under conditions otherwise equal ultimate strength is dependent on the working of the metal. Kirkaldy found for round and square iron, as a mean of many trials, 4,050 (variations from 3,780 to 4,330); Wohler, for Borsig and Komgshütte round iron 4,110 (from 3,730 to 4,530); Knutt Styffe, soft puddled iron, 3,400 for round iron and 3,460 for square iron.

From seventeen trials of English rolled iron at three shops, Styffe obtained 3,910, (from 2,940 to 5,100); from sixteen with Swedish rolled iron, at four shops, 3,760 (from 3,170 to 4,900). Bauschinger obtained for Wasseralfingen rolled iron, 3,890 (from 3,750 to 4,140); for angle-iron at the Lothring works of six by six and seven by seven centimeter, 3,195. Kirkaldy's mean for angle-iron (many experiments) was 3,850 (from 2,910 to 4,310).

For Borsig rivet-iron, Wohler found from two trials 5,120; for English Homogeneous iron, three trials, 4,280. A piece from the head of an English rail gave to Styffe as average of three tests 3,380; another piece from the web, with two trials, 3,090; and a piece from Low Moor tire-iron 3,760. Bauschinger got for gas pipe perpendicular to direction of rolling, 1,400—1,500.

Styffe puts the strength of soft iron for tension at 3,380; Gerber and many others assign 3,500 for bridge construction; Reuleaux assigns 4,000; Von Kaven deduces from Kirkaldy's experiments for wrought-iron the average value, 4,200. For good iron, suitable for bridges, the ultimate tension must lie between 3,500 and 4,000.

Rolled figured-iron generally has little proof-strength and little tenacity; its use should be avoided as much as possible.

For iron wire suitable for bridge construction, Navier deduced from the experiments of Buffon, Telford and Seguin the averages 6,000, 6,360, 6,000; Mosely considered 6,580 as permissible, Reuleaux 7,000, Von Kaven (from Kirkaldy's results) 6,700; Laissle and Schübler, 5,000 to 8,000: 6,000 may be taken as a mean; but tests are always in order. The ultimate resistance to tension in plate-iron is generally less than for other sorts, and there is often a marked difference depending on the direction of stress. The value is generally greater for longitudinal than for transverse stress. Like relations appear in the kinds of iron used in bridges; but as the stress is generally only longitudinal, the matter is of less interest.

Kirkaldy obtained from a great number of plates, lengthwise, 3,570 (from 3,210 to 3,870), and transversely, 3,250 (from 2,920 to 3,550). On the other hand, Fairbairn, from four kinds of boiler iron, found 3,540 lengthwise (from 3,080 to 4,060); 3,620 across (from 2,940 to 4,330). From several boiler plates, Bauschinger obtained from twelve experiments, longitudinally, 2,820 (from 2,600 to 3,270); transversely, 2,730 (from 2,350 to 3,180). Boiler plate from the exploded locomotive "Fugger," gave in undamaged places, lengthwise, 3,040; across, 2,880. Stevens, in America, with the best Low Moor boiler plate, obtained, as a mean of five trials, lengthwise, 4,140 (from 3,890 to 4,500); and with cistern plate, a mean of six tests, 2,900 (from 2,320 to 3,670). Bauschinger obtained from a piece of decided fibrous texture, 2,910 along the length, 1,910 across. In tests of Goin & Co., Paris, the longitudinal strength was greater than the transverse; but for charcoal-iron in section only $\frac{1}{45}$, and for coke-iron $\frac{1}{5}$.

From Kirkaldy's experiments, Von Kaven obtains a mean of 3,800 for plate-iron. The English Admiralty requires for first quality 3,460 longitudinal, 2,830 transverse; for second quality, 3,150 and 2,680 respectively, warm and cold bending tests being required. Without special experiment the stresses should not exceed 3,000 longitudinal and 2,700 transverse. The ratio $\frac{9}{10}$, transverse to longitudinal, agrees well with Kirkaldy's mean and with the tests of Edwin Clark.

In the case of steel, the ultimate tensile strength depends largely upon the quantity of carbon and other ingredients; we shall return to this in another place. As the quantity of carbon is not always known, general results only can be given. Kirkaldy obtained as a mean of nine different kinds, 6,770, from 4,930 for puddled steel up to 9,340 for cast-steel. Sheffield Bessemer gave 7,840. Wohler found for cast-axle-steel from Krupp, Borsig, Vickers and Bochum, an average of 6,250, with eleven tests; from 4,020, for Vickers, to 7,670 for Krupp. Again, for heads of Krupp cast-steel rails, 7,380; for Frith tool steel, 8,400. In the case of hammered Bessemer round steel of from 0.86 to 1.35 per cent. carbon, Styffe found a mean of 7,730 (from 6,880 to 8,970), with eight tests; again, from rolled Bessemer steel, square and round, of 0.38 to 1.39 per cent. carbon, a mean of 6,480 (4,550 to 9,840), with nine tests; and for rolled Swedish round cast-steel of from 0.69 to 1.22 per cent. carbon, a mean of 8,910 (7,280 to 10,170), with four tests. We may assume for puddled steel 5,000; for good medium hard Bessemer steel, 5,500, to 6,500; for very good and hard cast-steel 8,000. The last value is given by Reuleaux, Laissle, Schubler, and others.

For Styrian cast steel plate (Bessemer) Bauschinger found as the mean of two tests 5,025 longitudinal and 5,180 transverse, Wohler, in five tests on Krupp's cast-plate-steel, found an average of 5,390 long. (from 4,900 to 5,770) and for that of Borsig 5,040 in one test. Tresca obtained 5,400 and 5,760 long. in two kinds of plate cast-steel; Stevens, with six tests on best English Bessemer steel 5,880 (5,240 to 6,090). For plate steel, longitudinal and transverse, 5,000 may be assured.

For the ultimate resistance to compression we have no experiments. It is hard to define it in a way practically sufficient. Bauschinger, in experiments on steel, found that a complete destruction of the material was hardly to be accomplished by compression, and he was of opinion with Rondelet, that metal yields sooner by bending than by crushing whenever the depth is more than three times the least transverse dimension. Rondelet, and after him Navier, put ultimate strength for compression at 4,950, Moseley at 6,580; and Bauschinger found the resistance of Bessemer steel considerably greater for compression than for tension. Though in Wohler's and Spangenberg's experiments the fracture always first occurred on the tension side, it does not necessarily follow that the metal yields to one strain more than to the other; and it is safe to assume an equality of working-resistance for tension and compression. But it is assumed that crippling of the compressed parts is not to be feared. Fairbairn, in several tests with compound plate-beams, observed that the fracture began in the upper flange; since that time care has been taken to stiffen as required, and to provide a rigid flange.

EXCESS OF ELASTIC LIMIT.

The limit of elasticity is generally defined as that stress per square unit beyond which permanent changes of form occur, while under less stresses the body returns to its former condition. Reference is made, not to sudden changes in stress and shocks, but to gradually increasing strains. But the definition is theoretically worthless, for a limit so definite is not probable, and much less is it proven. On the contrary, Hodgkinson and Clark have observed that there are permanent changes of form under very small loads. At present we must be content with defining this limit with Fairbairn, as that stress below which the changes in form are approximately proportional to the forces, while above this they increase much more rapidly. The words "approximately" and "much" are not so indeterminate as might be supposed, for, in the experiments of Bauschinger, the passage beyond the limit of elasticity could be determined very precisely; as for example in tension; "for with the same increase of load a disproportionately great elongation occurred at once, the maximum of which was in every case reached after some time," This sudden elongation must be credited to permanent changes of form; elastic elongations until near the breaking limit remain proportional to the stresses, and the modulus of elasticity is always found to be independent of the latter.

In the first definition the changes of form which are permanent from Bauschinger's point of view are neglected. All experiments, up to the present time, have shown that when the elastic limit is passed, the tensile resistance is considerably increased, while ductility and tenacity diminish; the metal becoming brittle, and having little power of resistance to shock. In experiments at the Woolwich Arsenal, an iron rod, four times ruptured by pull, gave the successive values of *t:* 3,520, 3,803, 3,978, 4,186; Bauschinger tore apart a piece of iron seven times, and the resistance increased from 3,200 to 4,400.

Paget found that iron chains after stretching bore a greater dead weight, but had less resistance to shock. Fairbairn thought all these phenomena could be explained by the hypothesis that the resistance of all the parts was not at first called into action, but, like ropes, they became gradually strained in common under sufficient load. With this accords the fact that Bauschinger observed that increase of resistance, especially in rolled iron, was notably regular when the stress was in the direction of the fibers. The analogy holds further; for a rope, when tense, is more easily broken by shock. And this explains why a rod under sudden increase of stress breaks more readily than in case of gradually increasing tension.

When the limit of elasticity is passed, this limit is again raised. Tresca, in tests of rails, succeeded in pushing the limit of elasticity to near the limit of rupture, the modulus diminishing by about one-tenth.

The practice hitherto has been to assume as permissible stress (b) a fraction of the elastic limit. In this case b increases with the number of loads. But the material becomes more brittle, and less resistant to shock, and local passages beyond elastic limits are not excluded. So that we need not assent to the often-advocated opinion that a test of material beyond the elastic limit would be of advantage. It is worth mention that the increase of resistance with the passage beyond each limit cannot go on indefinitely; but a diminution must occur at some time, unless we assume that with very gradual increase of stresses and longer intervals, the original resistance becomes greater than the initial ultimate strength.

Now, if passage beyond the elastic limit can work unfavorably, it should not be permitted. But it is enough to know that, according to the numerous experiments of Styffe and others upon all sorts of iron and steel, the ratio of elastic limit to ultimate strength generally lies between $\frac{1}{1.4}$ and $\frac{1}{1.8}$, and under the most unfavorable circumstances seldom reaches $\frac{1}{2}$.

Wertheim and Styffe have attempted to establish more precise definitions of the elastic limit, but as they are not better, either theoretically or practically, than others, it would be superfluous to consider them. It is since the time of Hodgkinson and Clark that an empirical importance has attached to this limit; and it is still very narrow in its scope, because the limit, as above defined, is of no avail in case of sudden change of strain and of repeated stresses.

Vicat made experiments to determine the effect of lapse of time upon a dead load. He kept wires loaded up to three-fourths the tensile resistance, during thirty-three months. The one with heaviest load broke. Vicat inferred from this, and because the extension seemed to be proportional to the time, that every load beyond the elastic limit would, after lapse of time, cause rupture. Considering that very small loads cause permanent changes in form, it would be more correct to infer that any load, if given time enough, will cause rupture. Fairbairn thought he could prove this by tests on cast-iron girders. But we do not find that the results of his experiments warrant his conclusion. But the fact that under stress beyond the elastic limit the ultimate strength increases, leads to the conclusion that security against dead-load increases with time. But if it is objected that a decrease may follow an increase of ultimate strength, it must be admitted, in view of all that has been said, that the influence of duration of dead-load has not been clearly determined. That each load requires a certain time to cause its correspondent permanent change has been known since the time of Hodgkinson and Wertheim, and also accords with Fairbairn's comparison with ropes; and, again, it has been observed by Bauschinger. This also holds true for further changes in form; and if a rod stretched again when released does not at once return to its pevious condition, a so-called secondary action takes place. This was observed in Kupffer's experiments. Thurston thinks that in this he has discovered a new phenomenon; that ultimate strength and elastic limit increase after a strain greater than the latter, continued for twenty-four hours. But there is nothing new in it. That the tensile resistance of iron and steel is greater under the action of an electric current, and that the ductility is effected now one way, now another, by dipping the metal in acid, seem to be shown by detached experiments, but this needs conformation.

MECHANICAL TREATMENT. HEATING. HARDENING.

Elastic limit and ultimate strength are both increased when the limit of elasticity is exceeded; ductility and tenacity diminish. Since under rolling, hammering, and pulling the elastic limit in the affected places is certainly passed, and permanent changes in form take place, the necessary effect of such mechanical treatment is obvious.

Heating and slow cooling has an effect exactly opposite to that caused by passing the elastic limit, for the metal becomes more ductile and loses in ultimate strength. According to Tunner, the brittleness produced by mechanical treatment gradually decreases if the body is allowed to remain at rest. A wire which broke when bent to an obtuse angle, just after leaving the plate, increased in pliability within a few days, and continued to do so during some weeks.

That cold-rolling considerably raises the ultimate strength was clearly shown by Kirkaldy's experiments, *t* nearly doubling in value, passing from 3,220 to 6,260, while annealing reduced it to 3,580. Styffe had an iron rod, which had been previously annealed, hammered cold to half its original section; the strength was raised from 3,140 to 5,830. According to Kick, cold-rolled iron, often treated, is much more brittle than the common sort. It has been often observed that the ultimate resistance of cold-rolled metal is diminished by removal of the skin, the effect of rolling being materially greater at the surface. These phenomena and many others, having no apparent relation to one another, are all explained upon the hypothesis mentioned.

If the mechanical treatment is with heat, both influences operate, viz: passage beyond the elastic limit and heating. These must counteract, entirely or partially, and the metal may gain in strength, the tenacity remaining constant or increasing. In England the working of the metal is often repeated.

A body once annealed is further changed only by higher heat, unless, meanwhile, it has received some treatment with opposite effect. It follows, that the effect of annealing must be greater in the degree that the temperature is higher than that under the previous mechanical treatment. This was observed by Styffe.

Hardening produces upon steel and wrought iron an effect like that due to passing the elastic limit; with this qualification, that in the case of steel, not only ultimate strength and elastic limit, but also brittleness are notably increased. Hardened metal is not suitable for many purposes, because of its slight power of resistance to shocks. The process of hardening consists in plunging the red hot metal into some fluid, oil or water, which suddenly cools it. Brittleness may be somewhat reduced by gradual heating, and may be destroyed by annealing, together with all other qualities due to hardening. The effect of hardening is much greater upon steel than on iron; and in either case depends upon the chemical constitution and other conditions.

Tresca, by hardening, raised the ultimate strength of two kinds of plate steel from 5,400 to 8,784, and from 5,764 to 8,880. Wohler cut several bars from a hardened cast-steel axle and found that the strength of one was 9,209, while that of the other, which had been annealed, was 7,455. Numerous tests of the effects of hardening have been published by Kirkaldy; with which those obtained by Styffe agree in the main. It is shown by experiments made by Wohler, Heusinnger, Waldegg and others that metal contracts a little when hardened; Wohler finding that the contraction of a steel-rod of 33 mm. section was about 1 mm. to a meter in length.

With respect to the strength of welds we have the results of Kirkaldy's experiments. The decrease of ultimate tensile strength varied between 2, 6, and 43.8 per cent.; while ductility was diminished, especially that of steel. According to Nasmyth, the strength of welds depends mainly upon the thorough elimination of the flux employed to hinder oxydation.

A diminution of strength occurs in cutting screws, amounting, according to Kirkaldy, to from seven to thirty per cent. The cause may be that the hard surface of the rod is removed by cutting; it may sometimes be due to the checks made by sharp dies. This, as well as the hardening caused by the greater force applied, explains why screws cut by Kirkaldy with blunt dies held better than those cut with sharp dies. That the strength of screw-bolts of small diameter proved somewhat greater, is no cause of wonder; for Kirkaldy observed that the strength increased with diminishing diameter, which was to be expected because of the proportionally greater effect of rolling.

INFLUENCE OF FORM.

The form of a member may greatly modify its strength. The rod has less resistance per square inch of section than if it were limited by the dotted line. For the load at the right of the dotted line is transmitted only by the fibers contiguous to the angle to those at the left; the former, therefore, receive more than the average stress per square unit, and fracture will take place sooner at the angle. In consequence of the bending which must take place in the case represented in the figure, the stress is increased; and the load would also act unfavorably at the smaller end. We can now understand why Wohler found the strength of bars with abrupt change of section much less than that of bars with rounded fillets; for in the latter case the effect of the load was gradual. In several cases the strength in the first case was from $\frac{3}{5}$ to $\frac{4}{5}$ as great as in the second, under like conditions; but these experiments do not give permanent data, since the change of section and all the modifications mentioned in the last paragraphs must come under consideration. Experiments by Fietze have proven that the notches at the base of rails, which are intended to prevent their sliding along the track, are much more prejudicial than the ordinary theory supposes. And grooved axles, subjected to torsion, exhibit a like loss of resistance.

It is remarkable that a rod will bear a greater dead pull than if the whole rod had the smaller diameter or were grooved through a greater length. The contrary was to be expected. Vickers found that a rod with a very short groove bore 12,500 kil. per sq. cr.; while one turned down a length of 35 cm. bore only 9,440. In Kirkaldy's experiments with rolled iron, very short-grooved rods, of about 3-4 diameter in length, had an increased tensile resistance of about one-third.

These phenomena are hard to explain, but may, perhaps, be accounted for as follows. Each pulled bar bent under a heavy load because of the non-homogeniety of the material. The strain caused by the bending contributed to the breaking, but this was less, the shorter the turned portion. If this explanation is correct, then a very short rod must generally bear more dead pull than a longer of the same material and the same section. Whether this is the fact I do not know. Again, there must be a like difference with compression, and this has been verified by the observations of Bauschinger, and others.

Nearly all experiments up to this time, Wohler's included, have been made on plain bars. Fairbairn only has tested riveted girders with the special purpose of comparing the values of different kinds of sections. The girders almost always gave way by the lateral breaking or crippling of the upper flange, which we try to prevent now-a-days by bracing, especially by angle or T iron set at uniform distances. The relation of the strength of compound pieces to simple members has not been determined. But it is certain that this ratio greatly depends upon the efficacy of connections, so that more care should be taken in this respect than heretofore.

Railways in Victoria.—The Government proposes to expend on railways this year the sum of £540,000.

TERRESTRIAL MAGNETISM AND THE MAGNETISM OF IRON VESSELS.

By FAIRMAN ROGERS.

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I.

1. There are two general matters in connection with magnetism to which the attention of those interested in navigation may be directed.

First—Terrestial Magnetism; in which the seamen is interested on account of the action of the magnetic needle and its variations.

Second—the Magnetic Action of the Iron composing a portion, or the whole, of a ship and its machinery.

2. The fact that a steel needle magnetized by rubbing with natural magnetic iron or loadstone will point towards the north pole of the earth was at first attributed to some attractive power in that direction drawing the needle towards it.

The simple experiment however of floating such a needle upon water will show by the fact of the needle merely assuming the usual direction without moving towards the northern boundary of the vessel containing it, that the force acting upon the needle, is a directive force, not one of attraction for the needle as a whole.

Experiment further shows that if we pass a galvanic current, generated by any of the ordinary batteries, through a coil of wire, a magnetic needle suspended within this coil will place itself at *right angles* to the direction of the current.

It is therefore inferred from this and more elaborate experiments, that the compass needle points to the north in obedience to the law which causes it to take a position at right angles to currents which are passing around the earth in a direction nearly parallel to the equator, and from West to East. Whether these currents are wholly on the surface of the earth, or partly in the atmosphere, is a question not yet determined, but Faraday considers that currents in the atmosphere produced by the action of heat upon the component gases which are magnetic bodies will account for the diurnal variations which are observed.

Barlow wound wire round a globe in a direction as nearly as possible that of the supposed currents as indicated by observation, and then covering the surface with the engraved paper of the globe found that a magnetic needle suspended over different points of its surface acted, while the currents were passing, exactly as the needle does at the same points upon the surface of the earth.

3. The hypothesis that the earth is a magnet just as a sphere of steel might be, having two poles, North and South, also accounts for most of the phenomena observed as will be shown when treating of the dip, and the two hypotheses have been connected by supposing, as was suggested by Ampere, that a magnet owes its power to currents which are circulating around it in planes perpendicular to its axis as we have supposed in the case of the earth.

4. For the means of producing electric and galvanic currents, the reader is referred to any elementary books in which the different forms of battery are described; but it is necessary to notice that currents are readily formed by changes of temperature, or by the contact of bodies of different temperatures. Thus the most delicate instrument for comparing temperatures known to the physical investigator is Melloni's thermomultiplier, which consists of a number of bars of zinc and antimony so arranged that their ends are alternately soldered together and placed in a pile, the two ends of which may be subjected to different degrees of heat. Upon bringing any source or reflector of heat near one end of the pile, the other retaining its former temperature, a galvanic current is instantly set up, which being properly conducted away by wires, will indicate by its action in deflecting a magnetic needle the most minute changes of temperature.

Such action by the sun upon the earth

and upon the atmosphere must give rise to currents which possibly supply the whole magnetic force of the earth, and which, at least, manifest themselves in those diurnal and periodic variations, the determination of which is a part of the object of our observations in terrestrial magnetism.

While the larger portion of the variation is constant for any one place at a given time, there are small parts of it which vary continually, and there are magnetic storms which, sweeping in a regular track, show themselves upon all the instruments which are placed upon their path. We do not refer to thunder storms, but to violent changes of magnetic condition which are only visible through their action on the needle.

Such magnetic disturbances generally accompany displays of the Aurora Borealis, and observations made during the continuance of remarkable Auroras, especially in high latitudes, are interesting and important.

We may compare the constant part of the variation to the average height of the sea water along a shore—the diurnal and periodic part, to the tides recurring each day and varying with the seasons, and the irregular variations to those irregular changes in the tides due to change of wind and the effects of distant storms.

5. To whatever causes we may attribute the action of the magnetic needle, a large number of observations are required to furnish the data upon which the true theory is finally to be founded, and the numerical value which will serve as a basis for calculation.

These observations are at present directed to the *direction* of the needle at different parts of the earth's surface with reference to the true meridians or the geodetic north pole, and to the dip of the needle or the direction with reference to a horizontal plane, which a needle accurately balanced before being magnetized assumes after being magnetized.

In both these cases the *amount* of the directive force as well as the position assumed is to be measured.

The force acting upon the needle in the direction of the dip at any given place, is called the *total force* of the earth at that place.

In other words, the force acting upon the compass needle is not simply one in a horizontal plane directing the needle towards a magnetic pole, but it is a force acting in an inclined direction, which we divide for practical purposes and for convenience of observation and consideration, by a well-known device in Mechanics, into a horizontal component and a vertical component.

The compass needle being acted upon by this inclined force, the vertical component is neutralized by weighting the compass card near the south end of the needle, so as to keep it hanging in a horizontal position, while the horizontal component directs it into a north and south position. As is well-known, the vertical component force changes in value with changes of latitude, and the compass card requires readjustment by the addition or subtraction of weight at the south end to enable it to preserve its horizontal position.

6. We frequently speak in a rough way as if the needle pointed to a distinct magnetic pole different from the geodetic pole. This is not strictly true, for there appear to be two north magnetic poles and two south magnetic poles, and the poles of dip or those places at which the needle stands in a vertical position, that is with a dip of 90°, do not coincide with the places of maximum intensity of the total force.

In practice, in latitudes ordinarily visited by the navigator, this complication of the simple law is not important, since the variation at any given place will have a sufficiently slow and regular rate of change to be determined and predicted within practical limits.

This change of variation is caused by the change of position of these magnetic poles, or, at any rate, by some change of condition of the magnetic elements of the earth, which alters the position of these poles as it does the declination, dip and total force at all other places.

For a more complete consideration of this part of the subject, the reader is referred to more elaborate treatises on terrestrial magnetism.

7. The direction of the horizontal component can be readily observed, by comparing the direction of the needle with that of the true meridian, obtained by observations upon the north star, or

the sun, or by any of the means well known to seamen.

The deviation from the true north line is called the *variation of the compass*, and differs in different localities and at different periods. It also changes slightly at the same place during each day, giving us the diurnal variation.

This is, however, too small to be of practical importance to the navigator.

The variation is of the utmost importance, as in some localities ordinarily visited by the navigator, it is as great as 50° to 60°, or four to five points to the West, so that when heading due North, magnetic, the ship will be sailing N.E. or N.E. by E.

The accuracy of the determination of this variation, will depend upon the method used to determine the direction of the true meridian, and the means used to measure the angle between it and the direction of the needle.

On board ship the variation is usually determined by observing the magnetic bearing of the sun at noon, with an azimuth compass, or if in a harbor, the magnetic bearing of some distant object such as a building or lighthouse, the correct bearing of which from the ship is known from a chart.

Such determination is sufficiently accurate for ordinary purposes.

The more careful one with the portable declinometer, is described further on (11).

8. The measure of the intensity of the horizontal component is a matter of much greater difficulty and requires nice apparatus and indirect means of obtaining the result.

If a needle which has always the same amount of magnetism, is delicately suspended and deflected a certain number of degrees from the magnetic meridian, it will oscillate about that meridian, coming to rest more or less quickly as the directive force at the place is greater or less; and by using this magnet in different localities the *relative* force at those places can be measured.

There are however two conditions affecting the time of vibration besides the force itself, the amount of magnetism of the needle and its form and weight as affecting its oscillations.

As we cannot insure the first being constant in any needle, and as more than one needle must be used, if we wish simultaneous observations by different observers, some method of eliminating these conditions must be employed.

The amount of magnetic force of the needle itself, is determined by measuring its action upon another needle which is first vibrated under the action of the earth alone, and then under the combined action of the earth and the needle whose power we wish to determine.

The effect of its own mass upon the vibrations is determined by vibrating it first alone, and then with a known weight called the inertia ring, and comparing the result.

The instrument used for these observations in the Navy, and in the Survey of the Coast of the United States is in effect that designed by Gauss & Weber, and made by Jones of London, with such modifications as have been suggested by its use. Mr. Hilgard, of the Coast Survey, has lately devised an improved form which is much more convenient in practice.

DIRECTION OF NEEDLE.

The portable declinometer, which is used to determine the direction of the needle and the horizontal force, consists essentially of a hollow cylindrical magnet suspended by a single thread, so that it may turn with great freedom.

This magnet is closed at one end by a plane glass plate, on which an arbitrary scale is engraved, and at the other by a lens.

At a distance of eight or ten inches from the center of the magnet, and at the same height, is a telescope mounted so that it can be moved in altitude and in azimuth.

When the telescope is so directed that a certain central division of the magnet scale determined by experiment, is cut by the vertical hair of the telescope, the telescope then points in the magnetic meridian, and by comparing this direction with the direction of true north determined by astronomical observation, the declination or variation is determined with more accuracy than is obtainable with an azimuth compass or an ordinary surveyor's transit.

This same instrument is adapted to the determination of the horizontal force, or the force which, when the magnet is deflected from its position in the magnetic meridian, acts to bring it back to that position.

If the needle is thus deflected and then permitted to swing, it will vibrate until it comes to rest in the magnetic meridian, and it will vibrate with greater or less rapidity as the force drawing it into position is more or less strong.

But the rapidity of vibration will depend, with the *same* horizontal force, upon the magnetism of the magnet itself and this must be determined in order that we may compare experiments made with different magnets.

To do this the magnet observed upon, is dismounted and another substituted in the suspension, and the original one is placed at a measured distance usually from one and a-half to two feet from the suspended magnet in a line at right angles to the meridian. This magnet produces a deflection in the suspended magnet proportional to its own magnetic force and thus this force can be measured. This experiment is repeated with the magnet at different distances.

By making observations then with the original magnet suspended, the horizontal force at the station is determined without reference to the charge of the magnet itself.

There is still the inertia of the vibrating magnet to be eliminated, and this is determined by comparing its vibrations when loaded with a brass ring of known weight, with its vibrations when unloaded.

10. The details of arrangement of the declinometer are as follows. As the magnet must be shielded from the action of the wind it swings in a wooden box $4\frac{1}{2}$ inches long, 2 inches broad and 2 inches deep, from the top of which a glass tube 8 inches high and $\frac{8}{10}$ inch diameter rises, opening into the box at its lower end. On the top of this tube is a brass cap capable of being turned around upon its mounting and so graduated on its edge that the amount by which it is turned may be measured. Through the center of this cap passes the pin to the lower end of which the suspension thread is fastened and this pin can be moved vertically by means of a rack and pinion so as to raise or lower the magnet. Suspended from this pin by an untwisted thread of silk fibre, made of as few filaments as possible, is an open brass stirrup or cage which receives the magnet.

The magnets, of which there are two, are hollow steel cylinders of $\frac{7}{10}$ outside and $\frac{11}{20}$ inside diameters and 3.15 and 3.85 inches in length with a lens at one end and a plane glass at the other on which a fine scale is engraved.

The lens is usually in the north end of the magnet and the scale in the south end. These magnets are called collimator magnets; some of the other forms of instruments have solid magnets, which carry a small mirror to reflect a scale placed on the telescope. In this case the telescope must be one of short focus, while with collimator magnets the ordinary theodolite telescope can be used; the lens in the magnet being arranged to give distinct definition of the scale with such a telescope.

A solid brass weight of the same form and diameter as the magnets is also provided.

The box in which the magnet swings is provided with three levelling foot screws and with a screw by which it is made fast to the top of the wooden table on which it rests, which table is in turn supported by a tripod from the ground.

The table is sufficiently wide to hold the magnet box, and sufficiently long to take upon it the telescope at a distance of eight or ten inches from the center of suspension of the magnet.

The telescope used is in fact an ordinary small theodolite (about a five inch circle), which permits the telescope to have a motion in azimuth and altitude.

It should be finely divided and have two verniers to the horizontal limb. It is screwed on to the table in the proper position.

The magnet box has small windows in the ends of plate glass with parallel faces through which the magnet is observed.

A wooden rod about four feet long is so arranged as to be screwed to the bottom of the magnet box and carries, sliding upon it, carriages to receive the deflecting magnet and to hold it at a given distance from the suspended magnet and at the same height. Wooden blocks to fit into the magnet box on the sides of the magnet to hold it firm, a brass inertia ring, plummet, copper damper for calming the vibrations of the magnet, screw driver, thermometer, pocket compass, spare screws, spool of silk fiber, cement, a small circular mirror which fits into the end of the magnet box and sometimes a small lamp, complete the apparatus.

11. Observations with portable declinometer for declination (variation) and horizontal intensity.

The object is first to determine the direction of the magnetic meridian with reference to the true meridian. This is a matter of observation and not of calculation.

Secondly—To determine the relative proportions of the force of the earth and of the magnet employed, or $\frac{m}{x}$, and the product of m and x or mx, m representing the magnetic moment of the magnet, x the horizontal component of the earth's force.

From $mx=a$ and $\frac{m}{x}=b$, we will have

$$m=\frac{a}{x} \text{ and } m=bx, \quad \frac{a}{x}=bx \text{ or } x^2=\frac{b}{a}.$$

And the value of m can be obtained in a similar way.

Set up the tripod with the plummet over the marked point of the station, fasten the wooden table upon it with its larger dimension north and south, the magnet box end towards the south, for magnets which have the scale in the south end, level it as nearly as possible, then fix the magnet box upon the table, screwing it up until the long brass spring comes into action.

By means of the three foot screws of the magnet box level it; observe whether the glass suspension tube is tight and vertical.

Screw the theodolite into its place and level it carefully.

Take off the sides of the magnet box, remove the wooden stick from the stirrup, put the brass bar in the stirrup, and allow it to hang until the twist is taken out of the suspension fibers.

If it is necessary to put in new fibers, be sure that they are all equally stretched, so as to bear the weight and use no more than are necessary to sustain the magnet.

When the bar hangs quietly, turn the upper cap of the glass tube gently until the bar hangs in the magnetic meridian as nearly as can be judged. Replace the bar by the magnet, taking care that no turn is introduced into the suspension thread.

Direct the light into the south end of the magnet by adjusting the circular mirror. The magnet will hang in the magnetic meridian, and if the sides of the magnet box are not parallel with it, the table must be turned upon the tripod until they are so, after which the levels must be examined and the box and theodolite re-levelled if they are out. The magnet must be raised or lowered by the rack at the top of the tube and the theodolite adjusted until the scale of the magnet is distinctly seen through the telescope. The axis of the magnet must be now determined.

Direct the telescope to a division near the middle of the scale, clamp it and record the reading. Open one side of the magnet box, rotate the magnet in its stirrup, so that the scale will be inverted, read and record.

Repeat this several times, and the mean of the means of the readings will be the axial division of the scale. Example:

	Scale erect	Scale inverted
	71.0	84.2
	71.3	84.8
	72.0	83.6
Mean	71.43	84.2

77.81 is axial div. of scale.

Now direct the telescope to this division, and it will point in the magnetic meridian.

The direction of the astronomical meridian passing through the same point having been previously determined by any of the observations on the sun or the north star familiar to navigators, and marked, the angular difference between those two directions will be the declination or variation.

Note—After putting the magnet into the stirrup, it may be steadied and brought to rest by the wooden block which is made to fit into the magnet box. After the box is closed, the vibrations may be calmed, and the magnet brought to rest by the use of the screw driver which accompanies the apparatus, and which is generally magnetized so as to have its point a north pole.

Holding this in the hand on either side of the magnet box, while looking through the telescope, a very little practice will enable the observer to regulate the vibrations of the needle with great facility.

12. OBSERVATION FOR HORIZONTAL INTENSITY.

Put in the block to keep the magnet steady and to prevent a twist being introduced into the thread. Take off the magnet box, and screw the long deflection rod to its place under the box, replace the box, and the rod will extend to the E. & W. on both sides. Place the magnet carriages upon the rod. Place the magnet *with which* the vibration experiments are to be made, the longer one upon the West carriage with its North end to the West, and at a given distance from the center of suspension of the magnet.

Suspend the other magnet in the stirrup, taking care that it is at the same height as the deflecting magnet. If the suspended magnet is not horizontal, slide the brass ring upon it to adjust it.

Note the time and the temperature, (see form of record, Form I), then note the scale reading. As the magnet will not come absolutely to rest in a reasonable time you must read the divisions to which it swings to the right and left and their mean will be the true reading as in

Form I, line 7 152.5 157.5 Mean=155.0
and line 8 32.0 33.5 " =32.75
&c.

Reverse the deflecting magnet in its carriage, so that its north end will be east. The suspended magnet will move towards the other end of its scale.

Read and record as before, 32.0 33.5, &c. Reverse again, record and reverse, and there will thus be two readings for each position of the magnet. The difference between the means of these observations will be the angular distance through which the magnet is deflected. Form I, line 11.

Now place the deflecting magnet in the carriage, which is to the east of the suspended magnet, and observe and record as before, recording the temperature at the end of the observations.

The mean of the two differences thus obtained:

Ex. Form I, line 11, 122.17
line 16, 128.4
———
line 17, 125.28 is $=2u^d$

a quantity which enters into the formula to be described.

It is twice the deflection to either side of the magnetic meridian measured in divisions of the magnet scale. To determine the value of V, the effect which 90° of torsion in the suspending thread has upon the direction of the magnet, the following observation must be made:

The magnet being at rest, read and record the torsion circle at the top of the suspension tube, and read the scale of the magnet (line 19, Form I, 275° 40′, 80.2). Turn the torsion circle through 90° the numbers increasing, viz., from 275° 40′ to 365° 40′ (275°40′+90°=365° 40′), read scale and record, (line 20). Turn circle *back* 180° (viz. to 185° 40′) read and record (line 21) turn again to original position (line 22).

Take the differences and the mean will be the value of V in scale divisions.

The middle difference recorded (between lines 20 and 21), is due to 180° not to 90°, and we must therefore divide the sum of the differences 6.7+13.9+7.0 =27.6 by 4 to get the mean for 90°=6.9.

These scale divisions being arbitrary we must have their value in minutes of arc. This value is constant for the same magnet, and same instrument, but if any changes are made, it must be re-determined.

To determine it, bring the magnet to rest, and turn the telescope until it points to a division near one end of the scale, clamp all fast and read the scale and the verniers of the theodolite, unclamp the upper screw of the theodolite and turn the telescope towards the other end of the scale, read scale and verniers. The number of minutes passed over by the theodolite divided by the number of scale divisions passed over, will give the value of one scale division in minutes.

Example:

Theod. readings.	Scale readings.		
62° 55′	124.6	119.0	mean=121.8
67 34	28.1	21.7	" = 24.9
4° 39′=279′			diff. 96.9

$$\frac{279'}{96.9}=2'879=1 \text{ sc. div.}$$

Form I.

1 Horizontal Intensity.

2 EXPERIMENTS OF DEFLECTION.

3 Station, Philadelphia. Date, June 11, 1865.

4 Mag. C. 6 deflecting. Mag. C. 17 suspended.

5 Observer, F. R.

	Magnet.	North end.	Time. h. m.	Temp t	Scale readings.		Alternate means.		Diff's.	Dist.
7	West.	W.	10 30	70°	152.5	157.5	155.0			r=2.0 ft. log.=0.30103
8		E.			32.0	33.5	32.75	155.15	122.25	
9		W.			151.2	159.5	155.3			
10		E.			31.6	34.8	33.2	32.97	122.10	
11									122.17	
12	East.	E.			28 8	31 1	29.9	29.9	128.40	
13		W.			156.8	159.8	158.3			
14		E.			28.0	31.6	29.8	158.3	128.40	
15		W.	11 0	71°	157.0	159.5	158.2			
16									128.40	
17	Means.		10 45	70°.5				$2u^d$	125.28	

	Tors. cir.	Scale.		Diff's.			Log's.
19	275° 40′	82.2	78.2	80.2		$\frac{125.28}{2}=62.64=u^d$	1.79635
20	365° 40′	88.3	85.5	86.9	6.7	$1^d = 2'.879$	0.45924
21	185° 40′	74.0	72.0	73.0	13.9	$1+\frac{H}{F}$	0.00160
22	275° 40′	82.5	77.5	80.0	7.0	181′.01 .... $=u$	2.25769
23	Mean=v=			6.9		=3° 1′.01	

		Log's.		
24			Tan. u / Log. of r=0.30103	8.72181
25	v=19′.96		3	
26	5400′+v'	3.73399	0.90309 r^3	0.90309
27	5400 (ar. co.)	6.27761	½	9.69897
28	$1+\frac{H}{F}$	0.00160	$.2108=\frac{m}{X}$	9.32387

The value of V (line 25, Form I) is got by multiplying 6.9 scale division by 2′.879 to bring it to minutes of arc.

It will be desirable to repeat these observations with the deflecting magnet at a different distance, as for instance, 1.5 feet instead of 2 feet, as in Form I, r=2 feet, so as to be able to combine the observations.

Now having the value of u^d in scale divisions (line 19, 62.64), we reduce it to minutes of arc, applying the small correction $1+\frac{H}{F}$ obtained from observations for torsion, line 28, getting a value of u=3°1′.01.

Now m, the magnetic moment of the magnet, is to X, the horizontal force of the earth, as 1 is to the tangent of u, multiplied by one-half the cube of the distance of the deflecting magnet, or $\frac{m}{x} = \tan.\ u\ \frac{r^3}{2}$, and, in Form I, performing this operation, we get $\frac{m}{x} = 0.2108$ as the ratio of the magnetic moment of the magnet to the earth's force.

The tangent of u enters into this formula instead of the sine, because the deflecting magnet is at right angles to the magnetic meridian, and not to the magnet itself, when it is deflected.

13. An improved instrument, the Theodolite Magnetometer, is coming into use, in which the divided circle is under the magnet box, and the reading telescope is attached to the magnet box, as are the arms which carry the deflecting magnet, so that the deflecting magnet is always at right angles to the axis of the suspended magnet when the telescope points to the axial division and the amount of deflection is measured on the circle directly in degrees and minutes. As in this case we are no longer limited to the length of the scale in the magnet, the deflecting magnet may be used at short distances, and the deflection u increased to a considerable amount, say 15° to 18°, instead of 3° as in Form I, thus adding to the accuracy of the results.

The objection to the apparatus as a portable one is, that it cannot be made useful for general surveying purposes as can the theodolite of the instrument described, and where the means of trans-

FORM II.

HORIZONTAL INTENSITY.

DEFLECTIONS WITH THEODOLITE MAGNETOMETER.

Station, Magnetic Shanty, Eastport, Me. Date, Jan. 15, 1860, P.M.

Mag. A deflecting at right angles to Mag. B suspended.

Distance r=1.35 ft. log.=0.13033.

Magnet.	North end.	Circle Readings. No.	A	B	Mean.	Circle Readings. No	A	B	Mean.
			° ′	′	′		° ′	′	′
East.	E.	1	63 15.5	15.0	15.25				
	W.					2	57 05.5	05.0	05.3
	E.	3	63 15.5	15.5	15.5				
	W.					4	57 05.7	05.5	05.6
	E.	5	63 15.0	15.0	15.5				
	Mean		63		15.2		57		05.4
West.	W.					6	57 06.0	06.0	06.0
	E.	7	63 11.0	11.0	11.0				
	W.					8	57 08 5	09.0	08.7
	E.	9	63 11.5	12.0	11.8				
	W.					10	57 07.0	07.5	07.3
	Mean		63		11.4		57		07.3

	° ′
Mag. E., $2u$=	6 09.7
Mag. W., $2u$=	6 04.1
Mean	6 06.9
u=	3 03.5

Beginning, Time 3h. 35 m., Temp. 34°.
Ending, Time 4h. 10 m., Temp. 35.5.

	Logarithms.
$\frac{1}{2}$	9.69897
r^3	0.39099
Sin. u	8.73515
$\frac{m}{X}$	8.82511

Observer, G. B. Vose.

Another observation, Jan. 16, with r=1.80 ft. gave $\frac{m}{X}$=8.83156.

portation are limited, this is a matter of some importance.

As generally made, the Theodolite Magnetometer is not well adapted for determining declination, but an improved form designed by Mr. Hilgard, of the U. S. Coast Survey, is so arranged as to obviate that difficulty, and to give many other advantages over the old instruments.

A form (Form II) is given for observations and computations with this instrument. In the computations it will be observed that the *sine* of u, and not the tangent as before, is used.

Having now determined the ratio of m and X, we must get an expression for their product mX, this product being equal to $\frac{\pi^2 K}{T^2}$, π^2K being a constant determined by a method which will appear further on, and T being the time of a given number of vibrations of the magnet which has been used as a deflector, when swinging freely under the action of the earth alone.

14. OBSERVATIONS OF VIBRATION.

To determine T we take off the deflecting rod and change the magnets, putting that one which was used as the deflector, into the stirrup.

Bring the magnet to rest, and turn the telescope until its vertical hair cuts the axial division of the scale.

By means of the magnetized screw-driver deflect the magnet about sixty minutes, (in the case of the instrument recorded in Form I, about 20 scale divisions) to either side of the magnetic

FORM III.

1 HORIZONTAL INTENSITY.

2 EXPERIMENTS OF VIBRATION.

3 Station, M. E. X. Date,

4 Magnet F. Inertia Ring, None.

5 Chron. A. B., No. 165, rate 1s.75 losing on mean time

	No. of vibrations.	Time.			Temp.	Extreme scale readings.		Time of 200 vibrations.	
6		h.	m.	s.				m.	s.
7	0	2	06	13.2	71°	97.3	55.5		
8	10		07	24.1					
9	20		08	34.6					
10	30		09	45.6					
11	40		10	56.5					
12	50		12	67.5		91.1	63.7		
13	200		29	51.4				23	38.2
14	210		31	01.4					38.3
15	220		32	12.4					37.8
16	230		33	23.5					37.9
17	240		34	34.2					37.7
18	250		35	45.6	72°	86.1	68.8		38.1
19		Means.			71°.5			23	38.0

20 Coefficient of torsion. Value of one scale div.=2'.879.

	Tors. cir.	Scale.		Diff's.			Log's.
21						v=19'.96	
22	275° 40'	82.2	78.2	80.2			
					6.7		
23	365° 40'	88.3	85.5	86.9		5400' + v'	3.73399
					13.9		
24	185° 40'	74.0	72.0	73.0		5400 (ar. co.)	6.26761
					7.0		
25	275° 40'	82.5	77.5	80.0			
26		Mean=v=			6.9	$1+\frac{H}{F}$	0.00160

meridian and wait until it vibrates steadily.

Then enter the time as shown in Form III, lines 7, 8, 9, 10, &c., of the 10th, 20th, 30th, &c., passage of the central division over the wire, and again of the 200th, 210th, 220th, &c., up to 250 vibrations. Note the temperature at begining and end—the thermometer being in such a position that it will show the temperature of the magnet as nearly as possible, and the extreme scale readings, showing the amplitude of the vibrations as in columns 4 and 5.

In column 6 carry out the time of 200 vibrations, as deduced from the difference between 0 and 200. 10 and 210, &c.

Make observations for torsion and determine $1+\frac{H}{F}$, exactly as in Form I.

Then for calculation, as in Form IV, enter the observed time of observations, apply the correction for rate of the

Form IV.

1 Horizontal Intensity.

2 CALCULATION.

3 $$T^2 = T'^2 \left(1 + \frac{H}{F}\right) \left(1 - (t'-t)\, q\right)$$

4	Observed time of 200 vibrations	=	s. 1418.00
5	Time of one vibration	=	7.0900
6	Corr. for rate	=	+ 0.0002
7	T'	=	7.0902

8				Log's.
9			T'	0.85064
10	q	0.00040		
11	$t'-t$	1°	T'^2	1.70128
12	$(t'-t)\,q$	0.00040	$1+\frac{H}{F}$	0.00160
13	$1-(t'-t)\,q$	0.99960	$1-(t'-t)\,q$	9.99983
14	$mX=\frac{\pi^2 K}{T^2}$		T^2	1.70271
15			$\pi^2 K$	2.21865
16			mX	0.51594
17			m	9.91990
18			$3.945 = X$	0.59604

19 * Experiments of deflection. Date, June 11, 1865.

20		$\frac{*m}{X}$	9.32387
21		mX	0.51594
22		m^2	9.83981
23	.8316	m	9.91990

chronometer used for observing, and thus get T′.

Enter the log of T′ in line 9, double it for T'^2, apply the correction for $1+\frac{H}{F}$ from Form III, and the temperature correction $1-(t'-t)\,q$, which is obtained as follows:

On the left hand side of the table, q (line 10) is a constant representing the change of magnetic moment of the magnet for one degree Fahr. of temperature, determined by the maker, or at a permanent observatory, and given with the instrument. (Riddell, page 89).*

In the example given, this quantity is 0.0004. Then t being the temperature of the deflecting magnet in the observations of deflection which are to be used with these observations, and t' the temperature of the same magnet now suspended, the difference $(t-t')$, in this case 1°, is multiplied by the correction for 1°,q, (line 12, Form IV) and added to or subtracted from 1, according as it is positive or negative (— if t' is less than t, and + if it is greater).

Its log is then entered in the right hand column, and the log of T^2 found by adding logs in lines 11, 12, 13.

From previous investigations

$$mx=\frac{\pi^2 K}{T^2}. \quad \pi \text{ is } 3.14\,159.$$

K represents the moment of inertia of the magnet and its stirrup the weight of which evidently modifies the time of vibrations.

K is determined by the formula

$$K=W\left(\frac{r_i^2+r_e^2}{2}\right)\frac{t^2}{t'^2-t^2}$$

in which r_i and r_e are the internal and external diameters in inches of the brass inertia ring and W its weight in grains, t' the time of one vibration of the magnet with this ring and t without it at a certain temperature.

The log of π^2K is usually furnished to the observer with the instrument, but it may be obtained by a series of experiments with and without the inertia ring, the ring being carefully balanced on top of the magnet by aid of the wooden blocks which keep the magnet steady.

Subtracting the log of T^2 from that of π^2K we get the log of mX as in line 16.

Taking $\frac{m}{x}$ from the deflection experiments, referring to the date as in line 19, and adding its log and that of mX, we get the log of m^2 and consequently of m, and then (in line 18) the value of X.

15. INCLINATION OR DIP.

The instruments used to determine the inclination, are more simple in principle than those described, but the observations are not always so satisfactory, as mechanical difficulties of construction are apt to give trouble.

The dip circle consists essentially of a steel needle from six to ten inches in length, hung upon a small and accurately finished cylindrical axis, and carefully balanced on that axis so as to stand indifferently in any position. This needle is hung in the center of a vertical graduated circle, in some very delicate way, generally upon agate planes. The circle is mounted on levelling screws, and turns on a small horizontal circle at its base.

When this needle, which is somewhat lozenge shaped and has fine points, is magnetized and placed so that its axis is at right angles to the plane of the magnetic meridian, it will assume the position of the inclination, and the circle having been previously levelled by its foot screws so that the line joining its 90° marks is vertical, the reading of the point of the needle is the dip.

In order, however, to eliminate the errors which may arise from want of perfect balance of the needle, from want of symmetry of form, and from imperfect division of the circle, it is necessary to make observations in different positions and to take the mean of the readings as the result.

For instance to observe according to Form V. Enter station, date and numbers of circle, and of needle, lines 2 and 3, Form V. Each needle will be found to have one end marked, and we will begin with a needle the marked end of which has north polarity, that is the marked end will dip below the horizon when in the circle.

* The temperature corrections may be determined by the observer, by using the deflecting magnet in its bar as in the observations for Form I, and noting the change of direction, produced by change of temperature, produced artificially.

They are usually very small, and owing to the difficulty of determining the exact temperature of the magnet, from the fact that it is never certain that the temperature of the surrounding air even close to the magnet itself is that of the magnet, and except in the very accurate observations of fixed observatories they may be neglected.

FORM V.

1 MAGNETIC DIP.

2 Station, Date,

3 Dip Circle No. 13. Needle No. 2.

4	POLARITY OF MARKED END NORTH.							
5	Circle East.				Circle West.			
6	Face East.		Face West.		Face East.		Face West.	
7	S.	N.	S.	N.	S.	N.	S.	N.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
8	71 55	72 06	72 25	72 36	71 50	71 50	71 00	71 00
9	72 40	72 43	71 40	71 55	71 30	71 25	71 38	71 30
10	72 33	72 38	72 20	71 44	71 29	72 18	71 10	71 03
11	71 50	72 01	72 17	72 05	72 12	71 30	71 12	71 16
12	72 14.5	72 22	72 10.5	72 05	71 45.2	71 45.8	71 15	71 12.2
13	72 18.2		72 07.7		71 45.5		71 13.6	
14	72 12.9				71 29.5			
15	71 51.2							
16	POLARITY OF MARKED END SOUTH.							
17	Circle East.				Circle West.			
18	Face West.		Face East.		Face West.		Face East.	
19	S.	N.	S.	N.	S.	N.	S.	N.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
20–23				Read	ings.			
24								
25								
26								
27	71 50.8							
28	Resulting Dip: mean of 71 51.2 and 71 50.8=71° 51′.							
29	Observer,							

Place the circle upon the stand or on a firm table, level it by the foot screws, and raising the V supports of the axis by the handle provided for the purpose, hang the needle carefully in the V*s* by its axis, with its *marked side* towards you, lower it steadily until the axis rests on the agates, and then let the V*s* drop below out of the way.

If the needle rolls out of position, raise it with the V*s* gently and replace it. Turn the circle by estimation at right angles to the magnetic meridian, and the needle will assume an approximately vertical position, turn the whole on its vertical axis until the upper point of the needle is exactly on 90°, record the reading of the vernier of the horizontal circle, then move the vernier of the horizontal circle if necessary, until the lower point of the needle is at 90°, turn the whole on the lower circle through 180° and repeat the reading of the upper and lower points.

The mean of these readings will be the reading of the lower circle when the needle is East and West, and at 90° from that reading the needle will be in the plane of the magnetic meridian.

Now having the marked end dipping, the face of the circle, that is the graduated side, facing east, and the marked side of the needle facing east, enter the reading of the south or upper end in column S, line 8 (Form V), and of the lower end in column N, same line. Take out the needle and reverse it, turning the marked face to the west, and read and record both ends, then reverse again, and repeat the reading, twice, three or four times as may be considered necessary. It will be found that the needle will not come exactly to rest very soon, and it is therefore better to read the divisions between which it vibrates and to take their mean as the reading, as it is done in the deflection experiments.

In Form V, lines 8 and 9, and 10 and 11, these extreme divisions are recorded, their mean being the point at which the needle would stand if it had time to come to rest, thus the mean 72 14.5 of the four readings is the same as the mean of the central reading of the two pairs 8, 9 and 10, 11. This is the best method of recording, except for an old observer, who is very expert at taking out the means in his head.

Turn the circle 180°, face to the West and repeat the observations as shown in the right hand side of form V.

Take the mean as in lines 12, 13, 14, 15. Now take the needle out, lay it upon the wooden block provided for the purpose, fasten it down with the brass clip and reverse its poles making the marked end now the south end.

To do this, place the needle in its block with its N. pole to your right, take the bar magnets which come with the apparatus, one in the right hand and the other in the left, that in the right hand with its north or marked end downwards, that in the left hand with its south end downwards; rest them on the needle near its center and draw them to the points, lift and replace them near the center and draw to the points again, repeating this movement half a dozen times. Turn the needle over with its other face up and rub in the same way.

The poles of the needle will then be reversed, that end which has been rubbed with the north end of the magnet having become the south pole.

This needle is then replaced in the circle which has been kept clamped in the plane of the magnetic meridian, and the second set of observations as recorded in the second part of Form V is made.

The final mean of both sets is the dip. Changing the magnetism of the needle eliminates any error that there might be in the mechanical balance of the needle. There is still a mechanical source of uncertainty from the irregularities of the pivots.

This is obviated by an arrangement suggested by Mr. Hilgard in which the pivots are so attached to the needle that they can be turned around and thus expose different sides to the agates. It is hardly necessary to say that great care must be taken that the pivots are not dirty or rusty, the magnets must be kept in their box with opposite poles at the same end and the soft iron keepers in their places. The needles must also be placed in their box with opposite poles at the same end. The small divisions on which they rest at each end are usually made of soft iron and thus serve as keepers.

16. The observations here described having been made and the results recorded they may be plotted upon a chart so as to exhibit the relations between them clearly to the eye.

The observations of declination, (or variation) having been plotted in sufficient numbers a continuous line is drawn through all the points of no variation, another through those of one degree variation, etc., until the chart is filled up. These lines, which are called isogenic lines or lines of equal variation will be found to form curves which are extremely irregular in their form and distribution, but of which, those representing Westerly variations cover at this time the Atlantic, the Eastern portion of the United States and Europe and Africa with a small portion of Eastern Asia where they come in as closed curves.

The lines of Easterly variation form

loops and closed curves in the center of the Pacific near the Equator.

These lines are laid down for every degree or for every five or ten degrees depending upon the scale of the chart; and the variation for any position between the lines can be obtained by interpolation.

Tables of the variation are given in the books on navigation (Bowditch's Navigator, Table LI). If the lines of equal dip are plotted it will be found that they are much more regular than those of equal variation, and that they approximate to the direction of parallels of latitude, the line of no dip being near the Equator.

This line is therefore sometimes called the magnetic equator. North of it, the north end of the needle points downwards, south of it south end.

The lines of equal horizontal force approximate also to the parallels of latitude, but not so nearly as those of equal dip.

The greatest horizontal force is near the Equator as should be the case even if the total force were everywhere constant, since as the dip decreases the horizontal component of the force must increase.

In addition to the obvious and simple use of these collections of observations to the navigator they form the basis of the whole discussion of the magnetic condition of the earth, and are therefore being considered with all the refinements of mathematical investigation with a view of deducing the general laws and permitting the computation in advance, of changes in the direction and intensity of the magnetic force.

An admirable article upon Terrestrial Magnetism by Prof. Joseph Lovering, of Cambridge, in the American Almanac for 1837, is recommended to those who wish a further acquaintance with the subject.

It is only necessary to suggest to the observer that observations made in places hitherto little examined are more useful than those made in well studied localities, and great care and attention should be bestowed upon such observations.

17. Before going to the second part of our subject it will be desirable to call attention to some properties of artificial magnets.

Although a magnet may be of any form, or rather although any piece of iron or steel may be magnetized, we shall for the present confine ourselves to the consideration of a rod or bar, remembering that what is called a horseshoe magnet is simply a bar so bent that its ends are brought near to each other.

A rod when magnetized, has its two ends converted with magnetic poles one of which points towards the north when the rod is freely suspended. This end is sometimes called the marked end, sometimes the *red* end and the other the unmarked, or the *blue* end, being thus distinguished in certain pieces of apparatus.

When an iron bar having no magnetism is brought very near to one pole of a magnet, a temporary state of magnetism of a character opposite to that of the pole is *induced* in it. If the end of the soft bar is brought near the north pole of the magnet it becomes temporarily a south pole. If a rod of hard iron or steel is so placed the magnetism induced becomes permanent.

Thus to magnetize a steel bar or to change its magnetism as in Sec. 15, it is touched, or for the purpose of getting more energetic action, rubbed with a magnet, that end which is rubbed with a north pole becoming the south pole of the new magnet, and *vice versa*.

19. Again a bar may be made magnetic by the action of galvanic currents upon it, as when it is placed in the center of a coil of wire through which currents from a battery are passing, the ends become poles, the bar permanently retaining its magnetism if it is of steel, but losing it if it is of iron as soon as the current ceases or it is withdrawn from its influence. Upon the latter phenomenon is based the Morse telegraph.

Since currents are passing through and over the earth continually, a bar will be similarly magnetized by being placed in certain positions with reference to them, and it is found that a bar placed in the plane of the magnetic meridian, and the direction of the dip, or in other words, in the direction of the total force, will become a magnet, retaining its magnetism if of steel, and if of iron, losing it in proportion as it is moved into a position at right angles to the magnetic meridian when it returns to its inert condition.

This induced magnetism may be rendered stronger if while the bar is in position it is violently hammered or shaken. The magnetic distinction between soft and hard irons is based only upon their capacity to retain the magnetism imparted to them, and steel may be classed as a hard iron. If a magnet or compass needle is freely suspended and another magnet brought near to it, it will be found that the opposite poles attract each other and that the similar poles repel each other.

Thus if we approach the north, or marked end, of a bar magnet to the north end of the compass needle, that end of the needle will move away from the bar, while it will move towards the bar if it is reversed and the south end presented. This is true of temporary induced magnetism also, so that if one end of a bar of soft iron is presented to the north end of the needle that end of the bar immediately becomes a south pole by induction (18) and attracts the north end of the needle. If the *same* end of the soft bar is now presented to the south end of the needle, it becomes a north pole by induction and attracts the south end, so that soft iron attracts both ends of the needle unless some stronger action than that of the needle gives it for the time a particular magnetism.

With this short explanation of the action of magnets upon each other we will proceed to the consideration of the action of the compass on board ship.

METHODS OF STEEL MANUFACTURE.

By ROBT. F. MUSHET.

From "Bulletin of Iron and Steel Association."

A German Professor undoubtedly knows almost everything, and can enlighten even an old fashioned metallurgist, such as I am. But, let every tub stand upon its own proper basis, and if any one has discovered that pigs can fly, let not another man claim the merit of his discovery. I may have myself to discourse of pigs, as well as of Professors.

Rather more than eighty years ago, David Mushet decarburized crude cast iron by heating it in contact with an oxidizing atmosphere; by heating it when imbedded in sand; and by heating it in contact with iron scales, hematite iron ore, and oxide of manganese, reducing thereby the crude iron to the condition, first, of steel, and, ultimately, to that of malleable or soft iron. The quality of the steel and iron thus produced varied, according to the purity or otherwise of the crude iron operated upon. If, then, Turner's method and Jullien's method date earlier than my father's, let them be considered the original inventors. If not, then my father must have that credit, and, in fact, to him it is due. A very large trade has, to my knowledge, been carried on in Birmingham for at least forty-five years, in the manufacture of cast iron articles, softened into soft iron and semi-steel by my father's process of decarburization of cast iron, in contact with heated oxides of iron, manganese, &c.

Now, as to natural steel, Professor Heeren tells us that, from the earliest times, it was prepared by melting crude iron, in a refining furnace, with wood charcoal. In this matter Professor Heeren is completely mistaken. In the earliest times, as evidenced by the scoriæ which remain, iron was reduced from the richest of its ores by heating those ores, in contact with wood fuel, until a portion of the metal was separated from them, ranging from 10 to 20 per cent. of the entire metallic contents of the ore. The iron thus separated was not crude or cast iron, but was the softest, carbonless iron, soft as copper, but not malleable, until by reheating in a charcoal fire, it had absorbed as much carbon as was requisite to render it malleable. That was the malleable iron of the earliest periods, and thus was it produced at the iron-works of the Egyptian Pharaohs, in Arabia, by the Silures in the Forest of Dean, and by the African negroes, by whom this method is pursued at the present day.

This African iron manufacture has been fairly described by Mungo Park, Capt. John Duncan, Dr. Livingstone, and other African travelers. Of the scoriæ from the work places of the Pharaohs, I have been shown specimens by Mr. Hartland, a London banker, who visited, a few years ago, the site of those ironworks in Arabia. This carbonless soft iron was far more fusible than slightly carburized or malleable iron. Natural steel was unknown to these early workers, as it is still to African iron-makers, it was only in far more recent times that an enlarged and improved construction of the reducing furnaces enabled ironmakers to produce metal so far carburized as to be in the state of crude or cast iron. And this crude metal was by various methods decarburized, so as to constitute what has been termed natural steel. Natural steel has also been produced by deoxidizing the ore and carburizing the reduced soft iron in the same furnace; an operation requiring great care and nicety of manipulation to obtain steel of serviceable quality. Natural steel, which is only the product of the purest ores of iron, is not purified, as Professor Heeren intimates, by repeated refinings. It needs no refining, being already pure enough; but it is cut up, piled, reheated, welded, and again forged to increase its homogeneity. Such is the tendency of certain ores of iron, as for example the pure magnetic wootz ore of India, to pass during the process of reduction into the state of soft carbonless iron, rather than into the state of crude or cast iron, that when treated by Mr. J. M. Heath, in a small cold blast furnace, the hearth became wholly choked up with this soft iron, and it was only by the adoption of heated blast that this otherwise insuperable obstacle was overcome. As regards wootz steel, *i. e.*, the earliest kind of cast steel of which we have any record, if Professor Heeren had condescended to consult my father's "Papers on Iron and Steel," he would have displayed, perhaps, a little less ignorance of the subject upon which he assumes to instruct us, than he actually has done. Even a German Professor might learn something from the writings of the man who first reduced the principles of iron and steel making to a rational and intelligible form, whose sound and thorough comprehension of the subject he wrote upon contrasts remarkably with the interminable columns of empirical rubbish, which, from time to time, make their appearance on the much be-muddled subject of the manufacture of iron and steel.

Well, Professor Heeren tells us that, to produce wootz steel, wrought iron made by the direct process is cut into short pieces, and placed in small crucibles, with a few green leaves, which crucibles are then stopped with clay, and heated for a long time. Now, the Hindoo steelmaker would be as green as the leaves if he merely did this. What he does actually do is to place the bits of iron in the crucible, along with bits of dried wood, covering the charge with a leaf or leaves, to prevent the wet clay of the stopper from getting amongst that charge. The crucibles are heated for two or three hours, and are then allowed to cool. The buttons or cakes of wootz are found of various qualities; some wholly fused and converted into perfect cast steel; some partly steel and partly iron, more or less fused, and therefore, of course, not homogeneous. From these half melted wootz cakes, the Professor affirms that the Damascus sword blades are manufactured. As I do not myself know any of the "blades" by whom these Oriental scimitars are manufactured, I can not ask them whence they derive their material; but the wootz cakes will need a great deal of cutting, piling, and, as it were, double shearing, before the steel is fit for sword blades, or for cutting down the hostile "blades" for whose delectation they are intended.

What the Professor calls "the Mushet process" was my father's process of melting Swedish bar iron in crucibles, with the addition of the proper dose of charcoal in small pieces. The steel thus produced was supplied to the celebrated firm of P. Stubbs, of Warrington, and the then Mr. P. Stubbs preferred it for his saw files to the Sheffield steel of cementation, prepared by melting bars of double converted blister steel. The Vickers process alluded to by the Professor is, I presume, the employment of manganese in the melting pot, first suggested by my father's intimate friend, Josiah Marshall Heath, to whom and to my father, Elliott, the Sheffield Corn-Law Rhymer, affirmed that Sheffield owed one-half its prosperity. In fact, take away my father's carbon process, Heath's manganese process, and my spiegel process, and Sheffield trade would shrivel up like one of the Professor's green leaves in the wootz crucible.

Well, poor Heath was driven, broken-hearted to his grave, by the grasping avarice and corrupt machinations of the then Sheffield steelmakers, and by the impenetrable stupidity of Judge Abinger and his legal brethren, who, unable to get inside a melting pot or into their own stomachs, would not believe what takes place therein. Charles Dickens has described, in far better language than I can command, the villainy brought to bear to effect the ruin of Mr. Heath.

Again, Heeren informs us that English cemented steel is made of wrought iron of the best quality, mixed with charcoal, and heated for two or three weeks. Quite a mistake. Iron, of qualities ranging from £3 to over £30 per ton, is converted, but not by heating it for two or three weeks, for were that done, a big lump of cast iron, in place of converted bars, would be the product of the operation. This was once proved at the Mersey Steel Works.

I now come to the Professor's remarks upon puddling, which operation is practiced in a furnace heated with coal. All right, so far. But then, says the Professor, it is necessary to purify the product by repeated refining, or by transforming it into cast steel. Now the cinder, mechanically mixed with and adhering to the puddled balls, is the only thing, except scale, got rid of by rolling, squeezing, or forging, and this can scarcely be termed refining the iron, any more than the act of a man washing his dirty hands can be designated refining his fingers. And if the puddled iron be transformed into cast steel, it is not thereby purified, as the Professor may easily ascertain, by melting cinder puddle bars with carbon into cast steel.

Peter's process—unless the Professor means the process of collecting the Pope's Peter's pence—was anticipated by Anthony Hill, of the Plymouth Ironworks. Chenot's process is a mere modification of my father's process of producing cast steel direct from iron ore. I have specimens of cast steel thus produced by my father, from Cumberland hematite, in the year 1797, that is before Chenot and Professor Heeren were born. But Chenot did not melt his substances under pressure, as stated by the Professor, he compressed them first and melted them afterwards. Another blunder of the learned Professor.

Martin's steel is a kind of metallurgical myth, and his patents are a farrago of metallurgical nonsense, which no man living, and least of all the patentee, himself, ever could unravel or comprehend. These patents were prudently bought up by Mr. Siemens; otherwise, they might have furnished lawyers with matter about which they could split straws *ad infinitum.*

I almost fear to approach the subject of the Siemens direct process, for in his description of this process the Professor has out-Heroded Herod. He says, "The one is melted *alone, without* the addition of reducing material, at a very elevated temperature; then the iron is *reduced* and transformed into wrought iron, or into steel, by adding coal ! ! !" Was the Professor poking fun at the public when he wrote this ? Or was there lager beer on the Professorial brain ?

To improve steel, diverse substances, says the Professor, are added to it; silver, notably. Now there is not in commerce any steel containing silver, for certain sufficient reasons. First, silver forms no true alloy with steel but only mingles mechanically with it. Second, even one pound of silver mingled with 500 pounds of good cast steel, sensibly impairs the quality of the latter; and third, manufacturers decline to spoil their steel by such injurious and expensive additions. Coming now to what the Professor terms "Uchatius steel," I make a Latin quotation for the Professor's benefit : *Hos ego versiculos feci : tulit alter honores.* The so-called Uchatius or Atomic process is my own process, invented by me, and commercially carried out by me, five years before the date of Captain Uchatius's patent. I sold this steel to a considerable extent, on the Continent, at prices ranging from £ 84 to £ 120 per ton, long before Captain Uchatius brought his imperfect edition of my process before English steel makers. Moreover, the Captain's agents, Messrs. Lenz and Howard, were deputed to wait upon me at the Forest Steel Works, then in my possession, in order that I might make for them some marketable steel by my Atomic process, they having at the Chelsea Steel Works failed to do more by their process than produce a miserable little ingot, 14 lbs. in weight, of overhard cast steel, which, after I had instructed the hammerman to treat it as tenderly as though it had been one of his own great toes, was at length drawn out into a much cracked, very scaly, and frightfully roky bar. Well, I made for the Uchatius deputies, by my Atomic process, half a dozen ingots, of 44 lbs. each, ranging from chisel to drill steel temper. Some were drawn into bars; and some were taken away, and were reported as being of excellent quality. Mr. Lenz also was profuse in his acknowledgments, and we parted to meet no more. After a considerable time had elapsed, I learned that the then Ebbw Vale Iron Company were exhibiting, at their London office, a bridge rail of cast steel, which Mr. Joseph Robinson, in his capacity of showman, informed inspecting visitors was a product of the Uchatius process; whereas the said rail was rolled from an ingot of Bessemer metal and spiegeleisen, cast by me, at the Forest Steel Works, for the Ebbw Vale Iron Co. This kind of proceeding savored to my thinking more of the "You cheat us," than of the Uchatius, process. Now I have no ill will against the defunct Ebbw Vale Co., on whose toes the black ox stepped heavily, not very long after. Nor do I grudge the £40,000 Captain Uchatius was said to have received, as a reward from the Austrian Government, for my Atomic process; but, as I have already remarked, let every tub rest upon its own proper basis.

Last, not least, I turn to the Bessemer process, and I find Professor Heeren stating that the common method is to completely decarburize the crude iron in the converter, and then add a rigorously-determined quantity of crude liquid iron. Here the Professor appears rigorously determined to ignore certain important facts, and to misrepresent others. Now the addition of liquid crude iron to decarburized Bessemer iron does not actually render the latter even less available for any practical or commercial purpose than it was before such addition had been made, and the simple reason is this: The crude iron will not eliminate from the decarburized metal the oxygen with which, during the blowing operation, that metal has become charged. It requires the presence of metallic manganese, with its superior affinity for oxygen, to eliminate the pernicious oxygen. Now metallic manganese being a notable constituent of spiegeleisen, I chose that spiegel, as a suitable addition to decarburized Bessemer metal, in order that, by the affinity of its metallic manganese, the oxygen might be removed; and so that the metal, thus purified, might become what it has ever since become, the grandest of all metallurgical inventions—Bessemer steel. When the lion, Bessemer, was caught in the toils, and the best lion in existence may at times be brought up, as it were, in sea phrase, "all standing," the little mouse, Mushet, came and nibbled the confining cords of the net, and the lion was set free from the toils. Now it appears to me that Professor Heeren, and indeed many other professors and metallurgists, are rigidly determined not to comprehend the Bessemer process. Much learning has, perhaps, deranged their perceptive faculties. Let me feebly attempt an explanation.

When cast or crude iron is blown in the Bessemer converter, until the whole of its carbon has been burnt out, the metal is what I have described as carbonless soft iron, not malleable, except at one particular temperature. It is also charged with oxygen, forced into it by the atmospheric blast. Now, before it can become a malleable, marketable commodity, it must get rid of its oxygen, and it must acquire some carbon. It wants, in fact, a combined tonic and drastic. In spiegeleisen I found, first, the drastic, namely, metallic manganese, to eliminate the oxygen, and second, the tonic, *i.e.*, the carbon necessary to impart malleability and steely properties to the Bessemer metal. There is the whole mystery cleared up; and the spiegel, being an alloy of manganese and iron, is no more crude iron, added to Bessemer metal, than brass is copper, or oroide pure gold. When cast iron, containing a notable alloy of metallic manganese, is treated by the Bessemer process, the subsequent addition of spiegeleisen is not requisite, the iron operated upon being in itself sufficiently manganesic. Such cast irons are employed in Sweden, and in other places on the Continent, where suitable manganesic pig irons are cheap enough. This process, however, demands great nicety and careful watching to insure uniform results. In England and America, and in most Continental Bessemer works, spiegeleisen is added to perfect the Bessemer process, and whatever Professor, professing to teach the world about the Bessemer process, suppresses these facts, respecting my spiegeleisen process, does himself an injury, by exposing his own ignorance, and does me an injustice by ignoring my process, and thus depriving me of the credit of my invention vitally essential as it is to the success, and indeed the very existence, of nine-tenths of all the Bessemer steel works in the world.

There is an alloy of iron and manganese, called ferro-manganese which is very rich in manganese, and well suited for addition to Bessemer metal, especially where very soft metal is sought for, as, for instance, for boiler plates. I did not claim this factitious spiegel, in my patent of 22d September, 1856, because even the name of ferro-manganese had not then been given, though the substance itself had been made by my father as far back as 1812, and by myself in 1849, and subsequently. But, as my patent claimed the addition of any alloy of iron, and manganese, containing also carbon, to Bessemer metal, my claim of course included the use of ferro-manganese, when that substance began to be commercially manufactured.

I now bid adieu to Professor Heeren, and to his metallurgical lucubrations. Should he ever see the observations I have made, and deign to refute them, I shall no doubt be terribly sat upon; for a German Professor has ever an inexhaustible fund of argument and logic to draw upon; and were one of these learned men to assert that we ought to wear our inexpressibles inside out, upside down, and hindside before, he would no doubt be able to support this doctrine by irrefragable arguments, so as to carry conviction to our minds.

THE CASE AGAINST IRON AS A BUILDING MATERIAL.

From "The Building News."

There are two sides to every question: and as the reasons in favor of iron as a building material have been stated and re-stated pretty frequently in modern times, it is desirable now and then to remind architects, and still more the general public, of the reasons against it. Professor Barry, in his first lecture this year at the Royal Academy, has referred to the subject, and has advocated, though in a cautious and sober way, the use of iron architecturally; or, in other words, the treatment of structural ironwork on artistical principles. This is very proper advice to give to engineers, or to architects who may have to do engineering work, in large railway stations and the like. It is, we think, dangerous advice to give to those who have to do with street architecture, and with public and domestic buildings generally. Architectural and engineering works, taking them in the mass, differ in one most important point: the former are in constant danger of fire, while the latter are not. An iron bridge is safe from fire: there is nothing combustible about it. An iron railway station (not a goods shed) is almost equally safe, if it is a large one—since the combustibles likely to be found in it are small in quantity compared to its size. It is altogether different with the combustible part of a house; a warehouse, or a theatre; and in many such buildings there is a great deal too much structural ironwork used already. Nothing burns down so fast as a building carried on cast-iron columns: witness the Surrey Music Hall, destroyed in half an hour. Nothing is so dangerous to firemen as what is fondly named "fireproof construction," and the reason is that it depends—in almost every case—on iron girders and rolled joists. It is easy enough to make a building fireproof, where small spans are allowable, and where, as in places for storage, piers are not in the way; but the system is too old to be patented, and so nobody has an interest in advertising it. All that is necessary is to have solid brick walls, brick piers, and brick vaults—and to avoid ironwork as you would gunpowder.

Every one knows that of the two, cast-iron yields to fire even sooner than wrought-iron. It loses a considerable percentage of its strength at about 200 degrees, and when red hot will not carry its own weight. The iron columns at the Surrey Hall, where not melted, were bent into all kinds of fantastic shapes, and twisted, some of them, like corkscrews. Wrought-iron, on the contrary, retains a good deal of its strength at a red heat; but a red heat is nothing compared to the temperature of a building in a great fire. Neither wrought nor cast iron is worth anything in this situation; and we have Captain Shaw's assurance that he would rather trust a stout wooden beam in a fire than any iron girder that ever was invented. One of the first duties of an architect, especially in towns, is to provide against fires; and his next duty is surely to make fires, if they happen, as little dangerous to life as possible. The use of iron in the form of girders and columns is well known to increase their danger greatly; and the more weight is put on it, the more deadly it is. The only remedy known is to cover it up with something that is really fireproof—such as brick, concrete, or plaster; but then what becomes of the everlasting cry that architects should treat iron artistically? The architect's first duty is to imbed it as deep as he possibly can in a different material, and not to show a particle of it, as a main structural feature, either inside or outside of his building. He may need to study the artistic treatment of this necessarily concealed construction; but this is quite a different thing from studying the artistic treatment of ironwork. Some day we may hope that a new Metropolitan Buildings Act will be passed, and that its framer will be clear-headed enough to see—what few of the general public do see at present—that to be incombustible is not necessarily to be fireproof. In that case we may be sure that provision will have to be made for imbedding or thoroughly casing with brick or plaster all the iron columns and girders that can possibly be so treated.

The first thing, then, that an architect has to with iron as a building material is to put it out of sight; and, in many cases, to do this so thoroughly that even its shape and general outline will no longer be discernible. His iron columns he may surround with brick or concrete so that they appear as columns still, though not as iron ones; but his iron girders will be safest buried in the very midst of his concrete floor. And even then neither columns nor girders will be anything like safe. Iron is so rapid a conductor of heat, that if only a few bricks fly off with the fire, or a few square feet of concrete crack and come down, both columns and girders will rapidly get hot, lose their strength and come down in a heap of ruins. Still one must risk something; and, as wrought-iron joists are very convenient, this amount of danger is not likely to put them entirely out of use. Cast-iron columns are more objectionable, even when encased; and rolled iron stancheons, riveted into a + or other strong section, might well be substituted for them. But, in any case, the net result is, that in the great masses of the buildings with which an architect is concerned, he will have few opportunities, however much he may desire them, of trying his skill on the artistic treatment of iron as a building material. If he does so, he will do it, more or less, at the general peril, in case of fire; and he ought, except in certain quite exceptional cases, to be prevented by law from doing it at all. The exceptional cases are those in which fire is not to be feared. There is, first, the class provided for in the present Act, in which a shed, or other uninhabited building, may be made of combustible materials if it stands far enough away from all other property. Iron might, of course, be exposed to view in a building of this sort, as it now is; but then there is not much scope for artistic design in the ironwork, any more than in the woodwork of a shed. It is not here, probably, that architects will be able to follow the enthusiastic advice so often given to them, to take up this neglected material and make it vie in effect with marble in the hands of the Greeks, or with stone in those of the mediæval builders. There remains, then, only the other class, in which the structure either has nothing combustible about it, or in which the quantity of combustible material is too small to do much harm in the event of fire.

The first thing that will occur to every one as to this class of work is, that it is mainly in the hands of engineers. It is of little use to admonish architects as to the way in which they ought to deal with a description of building, which, as a matter of fact, they never have to design. We shall, doubtless, be told, and with some truth, that they ought to design it, and that if they had been equal to the wants of the times some forty or fifty years ago, they still would have done so. Very possibly this may be the case; but we have to deal with the present day, and not with the earlier part of the century. At that time, the Classic school, whose praises Mr. Bentinck has just been sounding, formed almost the entire profession; and they were so busily engaged in imitating, as he tells us, the "finest works of the best masters," that they had no time to think about the new and pressing problems of the age they lived in. Besides, the best masters of the Classic school did not build in iron, and their works could not even be copied in it, though they might in stucco. Their disciples, therefore, patronized the plasterer, and let the iron-founder and the iron-roller find employment as they could. This was how work of this kind got into the hands of the engineers; and though since the happy "Decline and Fall of (so-called) Classic Architecture," a multitude of architects have adopted a sounder system, it cannot be expected that such work will immediately come back. The specialist custom, too, has arisen—less by the wish of architects than by the choice of the public, who cannot believe that any man can be eminent in more than one narrow department of his own profession: and, by this time, if no separate class of engineers existed, the architects who would have done engineering work would have been, in practice, quite distinct from those who do warehouses, churches, or houses. Still, however, they might have had an architectural training; and if they had been trained in any genuine architectural style—that is, in almost any except the "Classic" of our predecessors, they would have dealt with iron more economically, and far more artistically than the engineers have done. A man with artistic habits has the ambition of doing things in a pleasing way; but a coarse, merely practical man has no ambition above that of making the vulgar stare; and this ambition is far more costly than the other. The money that has been spent by engineers in trying to build roofs and bridges of wider spans than other engineers—where wide spans had no real advantage, would have made all the ironwork of our railway stations artistic. By artistic, we mean pleasing in form, truthful, and reasonable; not ugly in form, and plastered over with a quantity of trashy ornament, like the Ludgate-hill railway bridge, for example.

The conclusion from this head seems to be that there is room, and, indeed real need for a link between the two professions, in the shape of architectural engineers; engineers who shall be able to design as well as to calculate; architects who shall be able to build in iron, on a large scale, as well as in brick or stone. So far, Professor Barry's advice is very good advice for any one, whether architect or engineer, who has, or may have, the designing of railway stations, railway bridges, or other works of the same class. The point we insist upon is, that there is a vital and fundamental distinction between this class of work and all others; and that it is in this class alone that there is scope—if questions of practical safety have any weight—for the artistic design of structural ironwork. In this class of work the ironwork is visible; in all other classes it ought to be imbedded as deep as it can possibly be in brickwork or concrete. It is true that this is seldom done at present; but this, rather than the making iron ornamental, is the true end to aim at in the ironwork of public buildings and town architecture generally; and this, whenever the Metropolitan Building Act is revised and freed from its present absurdities, will, doubtless, become, to a large extent, imperative in London. Suppose, however, that this end is attained, and that structural ironwork is everywhere safe from fire, we have still some very serious faults to find with it. How long will it last, and how much of a building, in which iron is freely used, will remain when the iron fails? How many of our "great engineering triumphs" in iron construction will outlast the next century? When the Romans built a bridge or viaduct, the thing *was* built; it lasted, with fair play, for ten or twenty centuries, and may yet last as many more. When the modern engineer puts an iron tube, or a pair of lattice girders across a stream, all he has done is to find a temporary expedient for spanning it, which Nature, as if in scorn of its clumsiness, hastens to destroy. Every shower of rain takes something from its strength in the shape of rust; every passing train helps to make it more and more brittle by vibration. The time will not be long before all these iron bridges fail, and before the short-sighted policy which erected them will be a derision and a proverb of reproach. We forget how many tons of rust were scraped off the Menai Bridge, some five years after its construction, but enough to show that with the greatest care it could hardly outlast a century.

If this happened with so important a work only recently completed, we may judge what the case must be with other iron structures, longer built and more neglected. Six and twenty years ago, as many of us recollect pretty clearly, there was an universal flourish of trumpets over the new style that had been invented. Architects, we were told, were superseded; bricks and mortar had had their day; a new nineteenth century style of iron and glass had arisen, and Paxton was its prophet. The daily papers were in raptures, and predicted the universal advent of the green-house dispensation. The Sydenham Crystal Palace sprang up; its history has been a history of rust and breakages; its shareholders' profits have gone in vainly trying to keep it weather-proof; and its present state is such that, within the last few days, it has been publicly proposed to pull it down and build houses over the site. So much for iron buildings. Is it not likely that the same kind of failure will happen, if a little more slowly, to iron roofs? They are protected, it will be said, by painting; so was the Crystal Palace, with more care, probably, than most iron roofs receive. Painting, too, is liable to be neglected; in the long run is sure to be sometimes neglected—through oversights, through want of money, or through the desire of the managers of a company to show a larger margin of profit than they fairly can. The damage to a wrought-iron structure of one such period of neglect may be irremediable; and, even when there is no neglect, iron may go on rusting, under certain conditions, after it is painted. Whatever is done, rivets and rivet-holes cannot be painted where they are in contact; and so the most important part of the work necessarily becomes the most unprotected.

We have only hinted at the effects of vibration on iron, because the rate at which wrought-iron becomes brittle and crystalline under its influence has not been fully investigated. It may, or it may not, ultimately become a general source of weakness in iron structures. If it does, it will be a very serious one, because it will lead to sudden and not to gradual failures. We have said nothing, either, of the effect which the expansion and contraction of great masses of iron are sure to have, in time, upon masonry and brickwork; not so much in bridge-work, where the abutments are practically immoveable, as in wide-span buildings, where the walls are thin. There must be, in fact, a continual rocking backwards and forwards of the brick-work—to a very small extent indeed, but by a perfectly irresistible force—as the metal contracts and expands. The result of the whole will be that by the time the iron roof has rusted into a dangerous state, the brickwork and masonry will have been so pushed and pulled about that they will be about as worthless as the roof; and so the whole thing will come to an end together. In the words of Dr. Mackay's once-popular song, "We may not live to see the day, but there's a good time coming." London railway bridges, and London railway stations will not last very long; their "anti-human" ugliness is a nuisance which Nature kindly hastens to do away with; and their only use, in some five or six generations, will be to raise a laugh at the trumpery engineering of the nineteenth century.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—As this issue of the Magazine goes to press, the members of this society are gathering at New Orleans for the Ninth Annual Convention. The days of meeting are the 24th, 25th, and 26th of April.

The last number of the Transactions contains the following papers, viz., A Water-Conduit under Pressure, by J. T. Fanning: The Failure of the Ashtabula Bridge, by C. Macdonald: Co-ordinate Surveying, by H. F. Walling.

The Institution of Civil Engineers.—The second series of supplemental meetings for the reading and discussion of papers by students will commence on Friday, the 2d of March, and be continued weekly during the remainder of that month. The subjects to be dealt with at these meetings will be:—"On Fen Drainage at South Lincolnshire," by Mr. H. J. Tingle; "On Waves, and Structures designed to resist their Force," by Mr. W. J. Chalk; "On the Comparative Merits of Wrought-iron Plate and Trussed Girders," by Mr. R. J. G. Read; and "On Mechanical Puddling," by Mr. N. Watts. The gentlemen who have undertaken to preside on these occasions are, Sir J. W. Bazalgette, C.B., member of council; Mr. Abernethy, vice president; Mr. Woods and Dr. Siemens, members of council respectively. It has also been intimated that Dr. Siemens has been pleased to invite the students to visit his telegraph works at Old Charlton, on Saturday, the 7th April, at 11 a.m., when the various processes connected with the manufacture of telegraph cables and apparatus will be explained and illustrated.

IRON AND STEEL NOTES.

Tempering Spring and Tool Steel.—If steel is heated to redness and allowed to cool slowly, it becomes nearly as soft as pig-iron, and can be readily worked. If, however, when so heated it is suddenly cooled, as by plunging it into water it becomes very hard and brittle. Between these two extremities almost any degree of hardness may be given steel, and in diminishing its hardness to that point that has been shown to be the best for certain uses consists the art of tempering. With the explanation that seems almost unnecessary, that in tempering the steel is made very hard, and then its hardness reduced by heating it to a certain point indicated by the color of the steel, or, if heated in oil, by the color of the smoke or by flame, we give some rules to be observed in tempering. (1) The steel should be very hard before tempering. If the articles to be tempered are not properly hardened at first it will be time and labor lost to temper them. (2) The heat for tempering should not be too suddenly applied. The slower the heating the tougher and stronger the steel. (3) The most careful and experienced workman is liable to be deceived in the color of the steel, and consequently in the temperature in an imperfect light or at twilight. (4) Where water is used for plunging the steel in, the less frequently it is changed the better, provided it does not get greasy. The temperature to which the steel should be raised for various purposes is shown by the color of the steel when heated. Lancets which must be very hard, in order that they may be ground to a keen edge, are tempered to the faint yellow tinge, equal to 430° Fah., while razors and surgical knives, which must be less easily broken, are tempered to the straw yellow, equal to 450° Fah. Pen knives are tempered upon an iron plate over the fire, the blades being laid upon it on their backs until they have acquired the full yellow color, equal to 470° Fah. Cold chisels and large shears for cutting iron must stand rougher usage, and are therefore tempered to a brown yellow, equal to 490° Fah., while the brown with purple spots, equal to 510° Fah., marks the tempering heat for axes and plane irons. Table knives are heated till they acquire a purple color, equal to 530° Fah., in order to let them down to the proper temper, and articles in which great elasticity is required, such as swords and watch springs, are tempered to a bright blue, equal to 550° Fah., while saws are brought to the highest tempering heat at which the dark-blue color shows itself. This temperature, about 600° Fah., is that at which oil boils and inflames, so that a bath of oil is very frequently used in tempering, the articles being immersed in it and the temperature ascertained either by a thermometer or by the volume and color of the smoke which rises from the oil. Some tools are annealed by plunging them into oil heated to 400° Fah., and allowed then to cool down in it. Small steel tools, after being hardened by chilling in water, are coated with tallow heated over a flame till the tallow begins to smoke, and then stuck into cold tallow. Large steel implements are set down to the proper temper by being heated in a kind of oven known as a muffle.—*Iron.*

Ironworks in India.—A Calcutta correspondent writes to us as follows:—"Having heard a great deal about ironmaking in India, the many previous attempts and as many failures, we decided on taking advantage of a holiday to pay a visit to the works of the 'Bengal Iron Company,' which we had heard described as being the most promising of any attempt hitherto made.

"The causes of the previous failures were various, the most prominent being the supposed impossibility of making good iron with the coal which is so plentiful here, and the consequent expense of using the limited supply of wood charcoal available. But as has now been proved, the real cause lay not in the inferiority of the materials, but in the want of a competent manager. Fortunately for the success of the 'Bengal Iron Company' in their laudable endeavors to give the minerals a seventh trial, the directors secured the services of Mr. W. R. Whitelaw, who was at the time manager of the Govan Ironworks, Glasgow, where he had made himself a name for energy and ability in originating and completing several important improvements in the furnaces. The way he has performed his task here has shown that their confidence was not misplaced, and is in the highest degree creditable to himself.

"We venture to think that very few would have come to this country and done so much in so short a time without any previous experience whatever of the country or the people, who, as is well known, are peculiarly difficult to deal with.

"The Government had promised to lend their aid in furthering the enterprise by taking up land; but after some delay they found that there was not an Act to enable them to carry out this intention, so it was devolved on the company to look for themselves.

"The manager was accordingly instructed to fix on a suitable site, and, after a good deal of not very pleasant or honorable opposition on the part of several coal companies, a favorable position was secured for commencing operations, and also sufficient coal to carry on the works for a long time to come. Ground was broken on March 1st, 1875, close to the Burrakur branch of the East Indian Railway, between it and the Grand Trunk Road, which is within half-a-mile, thus securing all the advantages of easy and good communication with the coal and limestone quarries and with the markets for the produce, not to speak of the benefit of getting the materials for constructing the works in the safest and quickest way. The surrounding country is undulating, bare and barren, covered with a coarse gravel, and cultivated only in the hollows. But the gravel is good ironstone, and the surface of the ground has merely to be scraped to collect tons of it, several hundred tons having been got when making the foundations for the furnaces.

"The furnaces, two in number, are built on the open-topped principle, without taking the gas off. They are each fifty feet high, with a square base, built of stone found near the site, firebricks being only used for boshing and lining the barrels, fifteen inches thick. The barrels are round, as usual, and cased with iron. There are two hot-air stoves for each furnace, fired by coal in the ordinary way; two vertical blowing engines of 180 horse-power nominal, but capable of working up to 300 tons; two donkey engines for filling the boilers, &c., with a spare one in case of accident, and a pair of horizontal winding engines of twenty horse-power, for raising the materials to the furnaces. Steam is supplied to the whole of these from seven egg-ended boilers. The hoist, which is seventy-five feet high, is of a light and elegant construction, and stands between the two furnaces, the entire works thus presenting an exceedingly neat and compact appearance. The first cast was made just thirteen months after the ground was broken, and although at present only one of the furnaces is going, as much as twenty-five tons per day is turned out. At a short distance a large foundry is all but completed, which consists of three divisions, two of which are for castings, while the third contains an engine and boiler house, a machine shop, and a smith's shop, the whole block being 154 feet by 90 feet. Further up the slope are bungalows for the European staff with offices adjoining, and at the highest point of elevation, overlooking the whole, stands the manager's bungalow, all planned by himself. Some difficulty was expected in securing the necessary quantity of lime for carrying on the works, as the nearest was supposed to be above 200 miles off, but Mr. Whitelaw spent his spare time in scouring the country round about, and at last found magnesian limestone in abundance within ten miles of the works.

"There is an abundant supply of limestone for fluxing. The coal cokes well and is in abundance also, and easily worked, and the ironstone now being smelted is picked off the fields, the supplies underneath never having been touched. The industry promises to be a great success, and there is already over £100,000 sunk in the undertaking, Government not contributing a penny of it."—*Iron*.

RAILWAY NOTES.

The Narrow-Gauge Mountain Railway from Rostoken to Marksdorf in Hungary.—The Austro-Hungarian Blast-Furnace Company own extensive beds of iron ore near Rostoken, at an elevation of 920 feet above the Kaschau-Oderberger Railway, and 1872 it became the author's duty to lay out a locomotive line for the transport of an estimated yearly output of about 50,000 tons of ore to the station at Marksdorf, where the roasting was carried on; the gauge of the new line was optional, as no transfer of rolling stock between the two lines was necessary. The line was carefully laid out, but, owing to the nature of the country, extremely circuitous. The greatest bank, however, was only about 33 feet, whilst all tunneling was avoided The geological formation was decomposed slate and red sandstone. It presented a rough and abrupt outline, necessitating curves of 164 feet radius. The higher portion of the line was about 3.1 miles long, with a rise of 1 in 375, the total length being $12\frac{1}{2}$ miles, and the average gradient 1 in 40. The width of the gauge being 2 feet $4\frac{1}{2}$ inches, and the wheel base 5 feet 3 inches, the minimum radius of 164 feet was practicable, for Von Weber found that, in constructing the Brothal Railway, with a speed of about 9 or 10 miles an hour, the minimum radius could be 148 feet, the gauge being taken at 2 feet $8\frac{1}{2}$ inches. Deducting the number of non-working days and allowing for gradients, &c., it was found necessary to compose every train of 15 trucks, carrying 5 tons each, with a capacity of 3.27 cubic yards, and with a speed of nearly 5 miles an hour. The length of the trucks was twice the wheel base, and the breadth rather less than double the gauge, the height being half the breadth. These dimensions were arrived at from the specific gravity of the ore, which was 2.0. The heavy weight of the ore produced considerable wear and tear, and necessitated strong frames for the trucks, which were composed chiefly of iron in a proportion of about 40 or 50 cwts. per truck, and furnished with strong springs. Thus an empty train of 15 trucks had a gross weight of from 600 to 750 cwts., which had to be dragged up an average incline of 1 in 40 for about 8 miles. As this required an engine of 15 tons, and with two wheels the load of 7 tons per axle would have required a rail of 55 lbs. per lineal yard, it was determined to use a locomotive with three wheels coupled and tender. Bessemer steel rails of 38 lbs. per lineal yard we finally adopted. The principal duty of the engine was to carry back the empty trucks up 1 in 40, and thus the brake power became a serious question, the dead weight of the trucks being ingeniously used to assist in this purpose. Careful cross-sections were everywhere taken when laying out the line.

Watering places along the route of the steep incline were found essential, and in erecting them the signalling stations were fixed at the same points, and when practicable they were placed near public roads, so as to lessen the dangers incident to level crossings. The natural rock was largely used for ballast, with good results. The line was begun in April, 1873, and completed in September, 1874. Where it is single the average width of formation is $6\frac{1}{2}$ feet, but it varies with circumstances. The cuttings in rock permitted a slope of about 1 in 6; where the material for embankments was rock, the slope was about 1 to $1\frac{1}{4}$, and 1 to $1\frac{1}{2}$ where it was earth. The nature of the strata forbade tunnelling. The total cost of the line, about £44,000, including rolling stock, but exclusive of land, was equal to abont £3,800 per mile. The iron trucks cost about £107 each.—PAUL KLUNZINGER, Allgemeine Bauzeitung.—*Mining Journal.*

JAPANESE RAILWAYS.—The Japanese appear to have become thoroughly aroused to the importance of the construction of railroads in that country, and the Island of Niphon promises to be shortly as thoroughly traversed by steel rails as the most civilized country. The people are intelligent, and appreciate the importance of the new enterprise, and the population is dense. There are all the elements for the development of a first class, profitable system of railways. Osaka, a large inland town, is now connected by rail with Kobe, an enterprising seaport. The road has been built by careful engineers, and has three quite elaborate tunnels, one of which is 365 feet in length. The bridges are chiefly of wood, some of them eighty feet in length, and of very excellent construction. One bridge is a masonry structure, built in the most substantial manner, and another is an iron structure. The curves are frequent and some of them of short radius. Owing to the fact that a large part of the territory traversed by the road is irrigated for agricultural purposes, the number of culverts is very large. There is one piece of road where there are as many as thirty culverts to the mile. Two of these openings are arched bridges. The first is over the Shindin-gawa; the next opening is a wooden trussed girder bridge or stone abutments, and having one span of forty feet over the Shiku-gawa, the next is one over the Hiruta-gawa, which has two spans of thirty feet each, within a quarter of a mile of Nishinomiya station. The Muko-gawa is crossed by the first of the three bridges which form the distinctive features of this portion of the line, as the tunnels do of the other. The bridge is an iron "Warren girder" of twelve spans of seventy feet each, resting on iron screw piles of two feet nine inches diameter, having wrought-iron blades of five feet diameter and five feet pitch. In the stretch between this river and the next—the Kansaki-gawa—there is one curve, with a radius of a mile, and six flood openings varying from 100 feet to 180 feet in width, the spans being 20 feet each. They are built of granite to flood-level and backed with brick, nearly all the culverts here being identical in construction, and varying only in size. The iron bridge which crosses the Kansaki-gawa is identical in construction with that of the Muko-gawa, but consists of seventeen spans. A short stretch, containing five more culverts (the last of which, a sixty feet span, is bridged by small iron "Warren girders" instead of wooden ones), brings us to the other remaining iron bridge—that over the Jusho-gawa. This, though only of nine girders, is perhaps, the most striking to the eye of the three. The screw piles on which the bridges rest are shortest at the Muko-gawa, none there being longer than thirty-four feet and none more than twenty two feet in the ground. At the Jusho-gawa the longest are forty feet, of which thirty are in the ground, while at the Kansaki-gawa they reach to the length of sixty-four feet.

The termini of this road are fitted with stations covering large tracts of ground. That of Kebe covers 64 acres, and will contain side tracks amounting in all to over five miles of rail, with large buildings for traffic, workshops, etc. A pier 450 feet in length by 40 ft. in breadth has been built into the sea, with water never less than 20 feet in depth, along a large portion of it. The Osaka station has 40 acres, and five miles of rail in its side tracks. The works have all been performed under the direction of a first-class English civil engineer, Mr. John England.

ENGINEERING STRUCTURES.

THE PROPOSED OHIO BRIDGE LAW.—The Joint Committee of the two houses of the Ohio Legislature, appointed to investigate the Ashtabula accident, has reported a bill "to secure greater safety for public travel over bridges," which imposes certain restrictions on the construction of bridges, and gives directions concerning their inspection thereafter, such as have never been established by law in this country heretofore, we believe. The first section provides that all railroad bridges on standard-guage roads shall be proportioned to carry the following loads per lineal foot for each track, in addition to their own weight:

Span	Load per ft. lbs.
$7\frac{1}{2}$ ft. (or less)	9,000
$7\frac{1}{2}$ to 10 ft.	7,500
10 to $12\frac{1}{2}$ ft.	6,700
$12\frac{1}{2}$ to 15 ft.	6,000
15 to 20 ft.	5,000
20 to 30 ft.	4,300
30 to 40 ft.	3,700
40 to 50 ft.	3,300
50 to 75 ft.	3,200

	lbs.
75 to 100 ft.	3,100
100 to 150 ft.	3,000
150 to 200 ft.	2,900
200 to 300 ft.	2,800
300 to 400 ft.	2,700
400 to 500 ft.	2,500

In all bridge trusses, of whatever length, the several members in each panel shall be so proportioned as to sustain, in addition to its share of the uniform load as above stated, such concentrated panel load as is provided by the bill for a bridge of a length equal to the length of the panel.

Section 2 provides that every railroad bridge shall be so constructed as to be capable of carrying on each track, in addition to its own weight, two locomotives coupled together each weighing 91,200 lbs. on the drivers, within a space of 12½ feet for each locomotive, followed by cars weighing 2,250 lbs. per lineal foot covering the remainder of the span. The loads named in Section 1 must not strain any part of the material beyond one fifth of its ultimate strength.

Section 3 prescribes that all highway bridges shall be constructed to carry the following loads per square foot:

Span.	For heavy traffic.*	Other bridges.
	lbs.	lbs.
30 ft. (and less)	110	100
30 to 50 ft.	100	90
50 to 75 ft.	90	80
75 to 100 ft.	80	75
100 to 200 ft.	75	60
200 to 400 ft.	65	50

The floor-beam strength of each floor beam for each wagon way of bridges in cities and near large manufactories shall be not less than 13,500 lbs.; for other bridges, not less than 11,250 lbs.

Section 4 provides that the stress on the best quality of wrought iron used in bridges shall not exceed, in tension, 10,000 lbs. per square inch for long bars or rods, and 8,000 lbs. for short lengths; and against shearing, 7,500 lbs. For the best quality of wrought iron in beams, the strains must not exceed, in compression, the following:

Length in diameters.	Minimum strain— Square ends.	Round ends.
	lbs.	lbs.
10	10,000	7,000
10 to 15	9,000	6,500
15 to 20	8,000	6,000
20 to 25	7,500	5,500
25 to 30	6,800	5,000
30 to 35	6,000	4,000
35 to 40	5,000	3,500
40 to 50	3,800	2,500
50 to 60	3,000	2,000

If iron of inferior quality is used, the stress shall be proportionately less.

Section 5 directs that cast iron may be used in compression only, and in lengths not exceeding 20 diameters, with the same stress as prescribed for wrought iron in the act: "In shapes other than square or cylindrical, whether wrought or cast iron be used, the stresses shall vary accordingly."

The greatest allowable strains per square inch on wood in bridges is given in section 6 as 1,200 lbs. for oak and 1,000 lbs. for pine, in tension; and for these woods in compression, according to their lengths in diameters, as follows:

Diameters	Strain in Compression. Oak.	Pine.
	lbs.	lbs.
10	1,000	900
10 to 20	800	700
20 to 30	600	500
30 to 40	400	300

Section 7 makes it the duty of railroad companies or other corporations erecting a bridge for public travel, by contract or otherwise, to keep on the spot a competent engineer with power to reject any piece of material which may have been injured or may be imperfect from any cause.

Section 8 prescribes that all bridges used for public travel, of more than fifteen feet span, or having a truss, shall be inspected monthly by some competent person in the employ of the corporation owning the bridge, "for the purpose of seeing that all iron posts are in order, and all rivets screwed home, that there are no loose rivets, that iron rails are in line and without wide joints, that the abutments and piers are in good condition, that the track-rails are smooth, and that all wooden parts of the structure are sound and in proper condition, and that the bridge is safe and sound in every respect." This inspector is to report once in two months, under oath, giving a detailed statement of the condition of each bridge to the superintendent of the railroad, who must forward it to the Railroad Commissioner, who is to prescribe the form of blanks to be used by such inspectors.

Section 9 provides for the inspection of highway bridges.

Section 10 requires that all railroads in the State, within sixty days after the Act goes into effect, shall report to the Railroad Commissioner a detailed statement of all bridges on their lines of more than fifteen feet span, or having a truss.

Section 11 directs that the Governor, on the nomination of the Railroad Commissioner, shall appoint "some competent expert, at a salary not exceeding $3.000 a year, who shall have cognizance of the construction and maintenance of every bridge intended for public travel in this State, and who shall hold his office for the period of five years, unless sooner dismissed by order of the Governor for reasons affecting his efficiency, in which case such reasons shall be given in writing by the Governor." This expert must pass an examination as to his competency before a committee of three members of the American Society of Civil Engineers. He will be subject to the direction of the Railroad Commissioner, who will cause him to inspect any bridge which has been reported defective, officially or other-

* "City and suburban bridges, and those over large rivers, where great concentration of weight is possible, and on highways in manufucturing districts."

wise; if found unsafe, the Railroad Commissioner will prohibit its use until put in safe condition and so pronounced by the expert.

Section 13 directs that all persons having in charge the letting of a contract for a bridge of more than thirty-five feet span, shall submit to this expert a strain sheet and drawings of the proposed structure, before work on it is begun, and the expert "shall certify its correctness, if correct, and make such alterations as may be necessary, if faulty in design or scanty in materials, according to the standard prescribed in this act; and on the completion of such bridge, said expert shall critically examine the work in all its details, comparing and verifying the sections on the strain sheet with those of the actual structure, and if these last are insufficient, forbid the use of the work till the bridge is made sufficiently safe and strong."

Section 15 directs that there may be an appeal from the decision of the expert to the Railroad Commissioner.

Section 16 provides that the Railroad Commissioner shall stop the running of trains on railroads which neglect or refuse to comply with the act, aud provides punishments for false reports, etc.

Section 17 provides that the standard loads of narrow-gauge roads may be thirty per cent. less than those prescribed for other railroads.—*Railroad Gazette.*

ORDNANCE AND NAVAL.

The Latest Armstrong Gun.—Sir W. G. Armstrong & Co. have recently completed a breech-loading gun weighing a little over 39 tons, but called for convenience a 40-ton gun, which is by far the largest breech-loader hitherto constructed in this country. This weapon has just been the subject of trials at the proof ground belonging to the Elswick firm, situated some forty miles north of Newcastle. The experiment attracted a large number of British and foreign artillerists. This new 40-ton breech-loader is constructed upon the coil system, and is of 12-inch calibre. The breech mechanism follows generally the French pattern—that is to say, it consists of a removable breech screw, so cut away in the thread as to take its full hold by being turned through one-sixth of a revolution. This screw draws back upon a hinged shelf, on which it swings back clear of the breech. But though the gun is similar to the French breech-loaders so far as the screw is concerned, it is altogether different in the mode of stopping the gas. This is done by using a steel cup resting upon a slightly convex surface on the head of the breech screw. The edge of the cup is pressed by the screw against a step or shoulder in the gun, so that, when screwed up, the base of the cup is forced to take the form of the convex head on which it rests, and thus the lip is expanded against the circular surface which surrounds it. When the breech screw is opened, the cup recovers its form by its elasticity, and thereby releases its hold, and comes out on the screw with perfect freedom. The Elswick firm have made several smaller guns upon this principle, one of which fired upwards of 500 rounds in Italy with such excellent results that the Italian Government adopted the pattern, and ordered a very considerable number of these guns, many of which have been already supplied and are now in use. The experiments on the present occasion commenced with the trial of a breech-loader of this description, weighing 26 cwt. and of $4\frac{3}{4}$-inch calibre. This gun was fired with charges of from $7\frac{3}{4}$ lbs to $8\frac{1}{2}$ lbs. of pebble powder. The breech was opened after each round by the officers present with the utmost facility, and the stoppage of the gas was seen to be absolutely perfect. The mean velocity obtained with the lowest charge (viz. $7\frac{3}{4}$ lbs.) was 1491 feet per second; with the 8 lbs. charge it was 1543 feet, and was $8\frac{1}{4}$ lbs. it was 1555 feet. With the highest charge the velocity instruments failed to act. But the chief attraction of the day was, of course, the firing of the 40-ton breech loader. This was fired with a projectile weighing 700 lbs., and with charges commencing at 160 lbs. of pebble powder, and increasing by steps of 10 lbs. to 180 lbs. The velocities attained were very high, being 1564 feet per second with 170 lbs., and 1615 feet with 180 lbs. The last-named velocity was the lowest indication given by the two instruments used, but taking the average of both instruments and including the observations with the same charge on a previous day, the velocity for a charge of 180 lbs. with this gun is about 1650 feet per second. The highest pressure in the bore was 19 tons per square inch. The stoppage of the gas was just as perfect in the large gun as in the smaller one, and the breech was easily and rapidly opened and closed by one man accustomed to the work, and by the mere application of his hands, without using any tool whatever. The projectiles are of the simplest description, being neither leaded nor studded, but acquiring rotation by a copper band at the base which is forced into the grooves. At this trial the projectiles were fired into a deep bank of sand so as to be recovered after firing. On examination after recovery the copper band was found to have acted perfectly.

BOOK NOTICES.

Forests and Moisture, or Effects of Forests on Humidity of Climate. By John Croumbie Brown, LL.D. Edinburgh: Oliver & Boyd. For sale by D. Van Nostrand. Price $5.25.

The subject of this treatise is already beginning to attract earnest attention in this country; and the belief that the aridity of the Great Plateau, west of the Mississippi, may be cured by raising trees is even now bearing fruit in several regions, particularly in Kansas and Colorado.

The writer of this book has made the subject a study under circumstances exceptionally favorable. He has been an extensive traveller, is an eminent botanist, and has been for some time a resident of South Africa.

One of his former works (Hydrology of South Africa) afforded much valuable information on this same subject.

The present treatise begins with the primary phenomena of vegetation: the structure of plants, and the physiology of their growth.

This latter topic is expanded through two chapters, dealing particularly with absorption of water by leaves, and with the production of water by many varieties of plants.

Part II deals directly with the main subject under the sub-title of Effects of Forests on the Humidity of Climate, in separate chapters, considering in succession: Immediate effects of forests on humidity of the atmosphere; Effects of forests on the humidity of the ground; Effects of forests on marshes; in which the author cites instances to prove that as forests diminish marshes increase and vice versa; Effects of forests on the moisture of a wide expanse of country; Local effects on rainfall and rivers; Correspondence between rainfall and extent of forests.

The author quotes throughout from other writers, indeed he moderately styles the book a compilation. In summing up the mass of evidence, he concludes: "It appears to be established that there are cases in which an extensive destruction of forests has been followed by a marked desiccation of soil and aridity of climate; and some cases in which the replanting of trees has been followed by a more or less complete restoration of humidity,—or the planting of trees where there were none, has been followed by a degree of humidity greatly in excess of what had been previously observed; that there are cases in which the rainfall within forests, or in their immediate vicinity has been perceptibly greater than in the open country beyond; but there are also cases in which the dessication of lands once clothed with forests and fertile, and now treeless, barren and dry, may be attributable in part at least to other causes than the destruction of forests, and still other cases in which destruction of forests does not appear to have affected the quantity of rainfall over a wide expanse of country."

These separate facts the author regards as quite reconcilable with each other and adds finally:—"The effects of forests in retarding the flow of rainfall after its precipitation has been established, I consider beyond all question; and not less so their effect in maintaining a general humidity of atmosphere and of soil."

Traite Pratique de Photographic au Charbon. Par M. Leon Vidal. Paris: Gauthier-Villars. Price $1.80. For sale by D. Van Nostraud.

This little book is devoted to the single subject of Carbon Photographs. It has several beautiful pictures illustrative of the completed process.

Traite Theoretique et Pratique de la Fabrication du Sucre. Vol. I. Par E. J. Maumene. Paris: Dunod. Price $10.00. For sale by D. Van Nostrand.

The theoretical part of this work refers to the chemical structure of the sugars and the changes produced by fermentation processes. A large space is devoted to analyses. The illustrations are many and excellent.

The first volume only is as yet published. It is royal octavo size, and contains 620 pages.

Van Nostrand's Science Series.—No. 27. On Boiler Incrustation and Corrosion. By F. J. Rowan. Price 50 cents.

This little work includes, as its title implies, two very important subjects. The Author has carefully studied both subjects in different localities, and under such different circumstances, that his conclusions possess a world-wide value.

No. 28. Transmission of Power by Wire Ropes. By Albert W. Stahl, M. E. Price 50 cents.

This subject is gradually becoming more important. In Switzerland the plan of thus transmitting power has been thoroughly tried and with such success, that its extension into other countries is warmly recommended by leading engineers.

All the details of a working system are described, and the calculations of strains and quantities are given in this little book.

A Manual of Rules, Tables and Data for Mechanical Engineers. By Daniel Kinnear Clark, C. E. New York: D. Van Nostrand.

Our previous experience with this Author has led us to regard him as a safe guide in all matters relating to machinery and its economical use.

This volume, of about 1,000 pages, comprises the leading rules and data relating to practical mechanics.

The Author has aimed to give the results of the latest investigations, many of them his own and many more of different authorities, of whom over three hundred are quoted. It is illustrated with numerous diagrams.

One large octavo volume, $6.00 in cloth; $8.00 in half morocco.

Warp Sizing: A Practical, Theoretical and Chemical Treatise. By E. Webb. London: Simpkin & Marshall. Price. $3.75. For sale by D. Van Nostrand.

A short treatise, and as its title implies, of a technical character. The various materials employed in sizing are treated in separate chapters. They are—Flour, Starches, Tallow, Cocoa Nut Oil, Palm Oil, China Clay, Chloride of Zinc, Chloride of Magnesium. Then follows an account of Methods and Machinery employed, and some recent patents for improvements in the same.

Some folding plates illustrate the work.

Assainissement de la Seine. Paris: Gauthier-Villars. Price $8.00. For sale by D. Van Nostrand.

There are three volumes of this finely executed work, containing several maps and many illustrations.

It is a valuable contribution to that branch of Engineering which comprehends the fullest use of rivers in populous districts, and includes irrigation, water supply and drainage.

Les Progres de la Photography. Par A. Davanne. Paris: Gauthier-Villars. Price $2.60. For sale by D. Van Nostrand.

This comprises an account of all the late improvements in the photographic processes, including the treatment of the negative as well as the positive impressions. Carbon Printing receives a fair share of attention, and does also Lithographic Photography. It is an octavo volume of 205 pages, and well printed, with but few illustrations.

PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS. London: Printed by William Clowes & Sons.

We have received the following valuable papers:

On the Combustion of Refuse Vegetable Substances, such as Straw, Reeds, Cotton, Stalks, Brushwood, etc., under Steam Boilers. By John Head, Assoc. Inst. C. E.

The Repairs and Renewals of Locomotives. By Alexander McDonald, M. Inst. C. E.

Both papers are accompanied by abstracts of the discussions upon them.

SIGNAL SERVICE REPORT FOR THE YEAR 1876. Washington: Government Printing Office.

The report of what is termed by the papers the Weather Bureau, has come to hand in good season. It is in no way inferior to its predecessors in point of interest.

Some new features in the present report, will prove interesting to many who take no further interest in the generalizations deduced from the immense accumulation of details, of the Signal Service. Among these are a set of very neat maps, exhibiting separately the paths of storms for each of the twelve months during five years; also a general average of such paths on each of these maps. The extension of the International exchange of Signals, and the Circumpolar map exhibiting the locations of the foreign stations, are points of peculiar interest to all.

In a general summary of the work of the Bureau, General Myer says, of the duties expected of the service for last year:

"They have been to give protection to commerce by warnings on all of the Atlantic and Gulf coasts of the United States, and on those of the lakes; to watch the river-changes along their courses in the great river-valleys; to note at seasons the temperatures affecting canal-commerce; to carry telegraphic-lines, by which meteorological reports may be had, over regions considered impracticable for such constructions; to maintain a system of connected stations on the sea-coast; to take charge of the recognized system of voluntary meteorological observations on this continent, in addition to the regular system of the service; to secure the co-operation of foreign observers in foreign countries; to endeavor to aid directly all the farming population in the harvesting of their crops; and, finally, to put it in the power of every citizen to know each day, with reasonable accuracy, the approaching weather-changes.

"The Chief Signal Officer earnestly recommends legislation for a more complete organization of the Signal-Service. With duties now as extensive as important, and reaching directly more interests of the people of the United States than those of any other bureau of the War Department, it exists without laws providing for the permanent employment and grades of its officers, or the promotion of its enlisted men. This condition is found to seriously embarrass the work of the Office. The subject of such organization received last year careful attention, and was favorably recommended by the President to the consideration of Congress. The experience of the year has demonstrated the need of it. If the service is to advance to greater successes, it cannot be too safely guarded against possible hamperings. A bill providing for a permanent organization was passed by the Senate at its last session.

"The results for the year give cause for encouragement. The question of the useful preannouncement of approaching meteoric changes may be considered as settled by now six years of successful service. With each year of labor the paths for improvement have opened more plainly. The co-operation of scientists has continued, both at home and abroad. The uses of the work accomplished, the results to be hoped from that in the future, have been well appreciated. The popular support and the support of the press have not failed. Whatever there has been of embarrassment can be but temporary. The opportunities for rendering a public good remain to the service. The effort will be to use them."

MISCELLANEOUS.

AMERICAN COMPETITION.—Whilst the scissorsmakers of Sheffield find scissors made in Germany, of Sheffield steel, offered in Sheffield at considerably under Sheffield prices, the edge tool and general hardware manufacturers of the same town and of Birmingham and Wolverhampton, receive communications from important British colonies, directing that specified valuable miscellaneous hardware consignments shall be made up of American and not British products. This was a requirement from Australia by a late mail. By a more recent mail, a similar communication has been received from the Cape Colony. If American cutting tools had alone been specified, no great surprise would have been experienced ; but that general hardwares of American origin should be preferred at the Cape to those of English firms is very unsatisfactory news. There is reason to conclude that much of this preference is due to the indisposition of English exporters to adapt their manufactures to the necessities of the market. This will especially appear when we point out that the same mail has brought information that the Americans have devised a light plough to be drawn by native oxen ; and that the plough is being so favorably received, that it threatens soon to wholly destroy the excellent business hitherto done by many English edge-tool firms in the old Caffre mamootie. The Americans would seem to be not wholly undeserving of the success which they are earning. The lesson is very simple; and masters and men in this country ought long ago to have learnt it.

TELEGRAPH EXTENSION IN VICTORIA.—The electric telegraph has recently been extended to Lilydale, and a banquet to celebrate the opening of communication has been held.

VAN NOSTRAND'S
ECLECTIC
ENGINEERING MAGAZINE.

NO. CII.—JUNE, 1877.—VOL. XVI.

NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

VI.

THE CONTINUOUS GIRDER WITH VARIABLE CROSS-SECTION.

In the foregoing articles the discussion of arches of various kinds has been shown to be dependent upon that of the straight girder; but as no discussion has, up to the present time, been published which treats the girder having a variable cross-section and moment of inertia, our discussion has been limited to the case of arches with a constant moment of inertia. Certain remarks were made, however, in the first article tending to show the close approximation of the results in case of a constant moment of inertia to those obtained when the moment of inertia is variable. We, in this article, propose a new solution of the continuous girder in the most general case of variable moment of inertia, the girder resting on piers having any different heights consistent with the limits of elasticity of the girder. This solution will verify the remarks made, and enable us easily to see the manner in which the variation of the moment of inertia affects the distribution of the bending moments, and by means of it the arch rib with variable moment of inertia can be treated directly.

Besides the importance of the continuous girder in case it constitutes the entire bridge by itself, we may remark that the continuous girder is peculiarly suited to serve as the stiffening truss of any arched bridge of several spans in which the arches are flexible. Indeed it is the conviction of the writer that the stiff arch rib adopted in the construction of the St. Louis Bridge was a costly mistake, and that, if a metal arch was desirable, a flexible arch rib with stiffening truss was far cheaper and in every way preferable.

Let us write the equation of deflections in the form

$$mD \cdot \frac{EI_0}{mn^2n'} = \Sigma\left(\frac{Mi}{nn'} \cdot \frac{x}{n}\right)$$

in which n is the number by which any horizontal dimension of the girder must be divided to obtain the corresponding dimension in the drawing, n' is the divisor by which force must be divided to obtain the length by which it is to be represented in the drawing, m is an arbitrary divisor which enables us to use such a pole distance for the second equilibrium polygon as may be most convenient, I_0 is the moment of inertia of the girder at any particular cross section assumed as a standard with which the values of I at other cross sections are compared, and $i = I_0 \div I$ is the ratio of I_0 (the standard moment of inertia), to I (that at any other cross-section). For the purpose of demonstrating the general properties of girders, the equation need not be encumbered with the coefficients mnn', but for purposes of explaining the graphical construction they are very useful, and can be at once introduced into the equation when needed.

In the equation

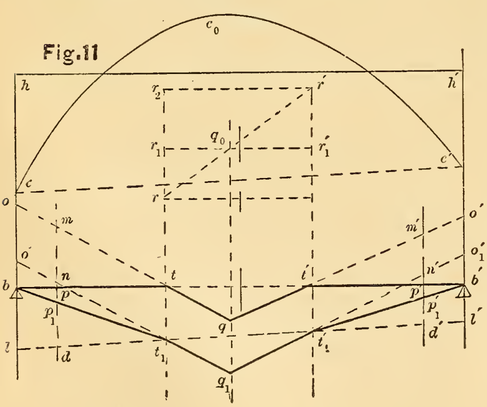
$$D \,.\, EI_0 = \Sigma_a^o (Mix)$$

the quantity D is the deflection of any point O of the girder below the tangent at the point a where the summation begins, and M is the actual bending moment at any point between O and a. These moments M at any point consist in general of three quantities, represented in the construction by the positive ordinate of the equilibrium polygon due to the weights, and by the two negative ordinates of the triangles into which we have divided the negative moment area. If we distinguish these components of M by letting M_0 represent that due to the weights, while M_1 and M_2 represent the components due to the left and right negative areas respectively, the equation of deflections becomes

$$D \,.\, EI_0 = \Sigma_a^o(M_0 ix) - \Sigma_a^o(M_1 ix) - \Sigma_a^o(M_2 ix)$$

Now let us take O at a pier at one end of a span and extend the summation over the entire span.

Fig. 11



If the piers are b and b' as in Fig. 11, let us suppose that O coincides with b and a with b'; also suppose for the instant that I is constant, so that $i=1$ at all points of the girder. Then we have

$$D_b \,.\, EI = \bar{x}_0 \, \Sigma_{b'}^b (M_0) - \bar{x}_1 \, \Sigma_{b'}^b (M_1) - \bar{x}_2 \, \Sigma_{b'}^b (M_2)$$

in which D_b is the deflection of b below the tangent at b', x_0 is the distance of the center of gravity of the moment area due to the applied weights from b, while x_1 and x_2 are the distances of the centers of gravity of the negative areas from b. In Fig. 11 let cc_0c' be the positive area due to the weights and representing $\Sigma_{b'}^b (M_0)$, while $\Sigma_{b'}^b(M_1)$ and $\Sigma_{b'}^b(M_2)$ are represented by hcc' and $hh'c'$ respectively. Let the center of gravity of cc_0c' be in qq_0, while the centers of the two negative areas are in tr and $t'r'$. Let the height of a triangle on some assumed base, and equivalent in area to cc_0c', be rr_2, then by a process like that in Fig. 2 it is evident that rr_1 and r_1r_2 are the heights of the right and left negative triangles, having the assumed base, on the supposition that the girder is fixed horizontally over the piers.

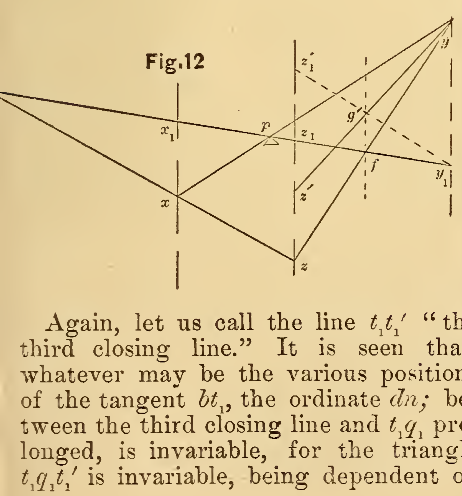
Now introducing the constants mnn' into the last equation and into the equation before that, the relation of the quantities is such that if the moments be applied as weights at their centers of gravity with the pole distance $pt = EI \div mn^2n'$, the equilibrium polygon so obtained will be tangent at the piers to the exaggerated deflection curve obtained when the distributed moments are used as weights; and the deflection at the pier b from the tangent at b' will be the same as that of this exaggerated deflection curve, and vice versa.

Let $pm = r_1r_2$, $p'm' = rr_1$ and $pt = p't$, then t and t' constitute the pole, pm and $p'm'$ the negative loads, and $pm + p'm'$ the positive load. Then is $btqt'b'$ the equilibrium polygon for these loads. The deflection of b below $b't'$ vanishes as it should in case the girder is fixed horizontally over the pier.

Now let the direction of the tangents at the piers be changed so that the tangents to the exaggerated deflection curve assume the directions bt_1 and $b't_1'$. Then the load line and force polygon assume a new position, such that t_1 and t_1' form the pole, and $dn = pm$ and $d'n' = p'm'$ comprise the positive load while np_1 and $n'p_1'$ are the new negative loads which will cause the equilibrium polygon $bt_1q_1t_1'b'$, which is due to them, to have its sides bt_1 and $b't_1'$ in the directions assumed.

There are several relations of quantities in this figure to which we wish to direct attention. It is evident that from the area cc_0c' whose ordinates are proportional to M_0, the actual bending moments due to the weights, another area whose ordinates are proportional to M_0i, the effective bending moments, can be obtained by simple multiplication, since i is known at every point of the girder. Moreover, the vertical through the center of gravity of this positive effective moment area can be as readily found as that through the actual positive moment area. Call this vertical "the positive center vertical." Again, the negative moment areas proportional to M_1i and M_2i can be found from the triangular areas proportional to M_1 and M_2 by simple multiplication, and if we proceed to find the verticals through their centers of gravity we shall obtain the same verticals whatever be the magnitude of the negative triangular areas, since their vertical ordinates are all changed in the same ratio by assuming the negative areas differently. Let us call these verticals the "left" and "right" verticals of the span. In case $i=1$, as in Fig. 11, the left and right verticals divide the span at the one-third points. This matter will be treated more fully in connection with Fig. 13.

Fig.12



Again, let us call the line t_1t_1' "the third closing line." It is seen that, whatever may be the various positions of the tangent bt_1, the ordinate dn; between the third closing line and t_1q_1 prolonged, is invariable, for the triangle $t_1q_1t_1'$ is invariable, being dependent on the positive load and pole distance alone. By similarity of triangles it then follows that the ordinate, such as lo', on any assumed vertical continues invariable; and when there is no negative load at t_1, then bt_1q_1 becomes straight, o' coincides with b and n_1 with p_1. Similar relations hold at the right of q_1. The quantity dp_1 is of the nature of a correction to be subtracted from the negative moment when the girder is fixed horizontally at the piers in order to find the negative moment when the tangent assumes a new position, for $np_1=dn-dp_1$. The negative moments can then be found from the third closing line and the tangents at the piers; while the remaining lines q_1t_1 and $q_1't_1'$ will test the correctness of the work. Before applying these properties of the deflection polygon and its third closing line to a continuous girder, it is necessary to prove a geometrical theorem from Fig. 12.

Let the variable triangle xyz be such that the side xz always passes through the fixed point g, the side xy always passes through the fixed point p, and the vertices xyz are always in the verticals through those points; then by the properties of homologous triangles the side yz also has a fixed point f in the straight line gp. Furthermore, if there is a point z' in the vertical through z, and in all positions of z it is at the same constant distance from z, then on the line yz' there is a fixed point g' where the vertical through f intersects yz'; for, if z' maintains its distance zz' invariable, then must any other point as g' remain constantly at the same vertical distance from f, as appears from similarity of triangles. But as f is fixed g' is also. When, for instance, the triangle xyz assumes the position $x_1y_1z_1$, then z' moves to z_1'

Let us now apply the foregoing to the discussion of a continuous girder over three piers $p''pp'$ as shown in Fig. 13, in which the lengths of the spans have the ratio to each other of 2 to 3. Divide the total length of the girder into such a number of equal parts or panels, say 15, that one division shall fall at the intermediate pier, and let the number of lines in any panel of the type aa represent its relative moment of inertia. Assume the moment of inertia where there are three lines, as at a, a_4, etc., as the standard or

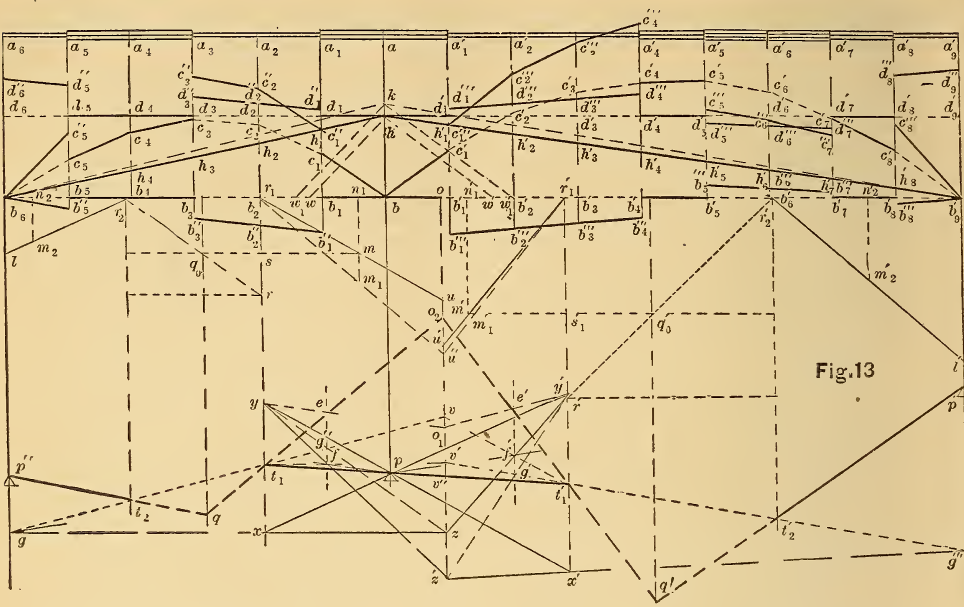


Fig. 13

I_0, then $i=1$ at a, $i=\frac{3}{2}$ at a_2, $i=\frac{3}{4}$ at a_6', etc.

Let the polygons c and c' be those due to the weights in the left and right spans respectively. There the ordinates of the type bc are proportional to M_0 in the left span. The figure $bc_1c_1''c_2''c_3''c_3c_4c_5c_5''b_6$ is the positive effective moment area in the left span, and its ordinates are proportional to M_0i. Its center of gravity has been found, by an equilibrium polygon not drawn, to lie in the positive center vertical qq_0. A similar positive effective moment area on the right has its center of gravity in the positive center vertical $q'q_0'$.

Now assume any negative area, as that included between the lines b and d, and draw the lines hb_6 and hb_9', dividing the negative area in each span into right and left triangular areas. Let the quantities of the type hb be proportional to M_1, hd to M_2, $h'b'$ to M_1', etc., then the ordinates of $bb_1b_1''b_2''b_3''b_3b_5b_5''b_6h$ are proportional to M_1i, and the center of gravity of this area has been found to lie in the right negative vertical t_1r_1. Similarly, the left negative vertical containing the center of gravity of the left negative effective moments, is t_2r_2. In the right span $t_1'r_1'$ and $t_2'r_2'$ are the left and right verticals. As before stated, these verticals would not be changed in position by changing the position in any manner whatever of the line d by which the negative moments were assumed, for such change of position would change all the ordinates in the same ratio.

Let us find also the vertical containing the center of gravity of the effective moment area, corresponding to the actual moment area b_6hb_9'. It is found by a polygon not drawn to be vo. Call vo "the negative center vertical." It is unchanged by moving the line d. If a polygon be drawn due to the effective moments as loads, two of its sides must intersect on vo, because it contains the center of gravity of contiguous loads. Now let rr' represent $\Sigma(M_0i)$:—it is in fact one eighth of the sum of the ordinates $b_1c_1+b_1c_1''$, etc., and hence is the height of a triangle having a base$=\frac{4}{3}bb_6$, and an area equal to the effective moment area in the left span. Also $r'r_1'$ is the height of a triangle having the same base, and an area equal to the effective moment area in the right span.

As previously explained, sr_1 is the amount of the right negative effective moment area in the left span, measured in the same manner, while sr is that on the left when the girder is fixed horizontally at the piers. We obtain $s'r_1'$ and $s'r'$ in the right span, in a similar manner. Now assume the arbitrary divisor $m=1$, and take the pole distance $r_1n_1=EI_0\div n^2n'$. Then as seen previously, if $mn_1=sr_1$,

ou is the constant intercept on the negative center vertical, between the third closing line in the left span, and a side of the type qt. Also ou' is a similar constant intercept on this vertical due to the right span. Make $r_2n_2=r_1n_1$ and $n_2m_2=sr$, then lb_6 is a similar invariable intercept; as is $l'b_9'$, which is obtained in a similar manner.

Now the negative center vertical ov was obtained from the triangle b_6hb_9', *i.e.* on the supposition that the actual moment over the pier is the same whether it be determined from the left or right of the pier. It is evident that while the girder is fixed horizontally at the intermediate pier, the moment at that pier is generally different on the two sides, at points infinitesimally near to it, but that when the constraint is removed an equalization takes place.

Since ou and ou' are derived from the positive effective moments, it appears that when the tangent at p is in such a position that the two third closing lines intercept a distance uu' on ov and the two lines of the type qt when prolonged intersect on ov, the moments over the pier will have become equalized.

We propose to determine the position of the tangent at p which will cause this to be true, by finding the proper position of the third closing lines in the two spans.

Move the invariable intercepts to a more convenient position, by making $o_1z=ou$, and $o_1z'=ou'$. Now by making the arbitrary divisor $m=1$, as we did, the ordinates of the deflection polygon became simply D, *i.e.*, they are of the same size in the drawing as in the girder, hence the difference of level of p'', p and p' must be made of the actual size. By changing m this can be increased or diminished at will.

Now we propose to determine two fixed points g and g'', through which the third closing line in the left span must pass, and similarly g''' and g' on the right.

If the girder is free at p'' then as shown in connection with Fig. 11, the third closing line must pass through g, if $gp''=lb_6$. Draw gz as a tentative position of the third closing line, and complete the triangle $xy'z$ as in Fig. 12.

Then is xy' the tentative position of the tangent at p, and since the third closing line in the right span must pass through y', and make an intercept on the negative center vertical equal to uu', then $z'y'$ is its corresponding tentative position. But wherever gz may be drawn, every line making an intercept $=uu'$ and intersecting $t_1'r_1'$ in such a manner that the tangent passes through p must pass through the fixed point g', found as described in Fig. 12. Therefore the third closing line in the right span passes through g'. Similarly, if there were more spans still at the right of these, we should use g' for the determination of another fixed point, as we have used g to determine it.

Now find g''' and g'' precisely as g and g' have been found, and draw the third closing lines t_1t_2 and $t_1't_2'$. If t_1t_1' passes through p the construction is accurate. Make $uu''=vv''$, then is n_1m_1 the negative effective moment at the left, and $n_1'm_1'$ that at the right of the pier.

Let bw be the effective moment area corresponding to the triangle hbb_6, and measured in the same manner as the positive area was, by taking one eighth of its ordinates, and let $bw_1=n_1m_1$; then as the effective moment bw is to the actual moment bh corresponding to it, so is the effective moment bw_1 or n_1m_1 to the actual moment bk corresponding to it. The same moment bk is also found from $n_1'm_1'$, by an analogous construction at the right of b, which tests the accuracy of the work.

Several other tests remain which we will briefly mention.

Prolong $p''t_2$ to q, and $p't_2'$ to q', then qt_1 and $q't_1'$ must intersect on the negative center vertical at o_2 so that $o_2v''=ou''$. Also vv' must be equal to uu'. Again t_1v' passes through f, and $t_1'v$ through f'. Also yo_1 intersects qo_2 on the fixed vertical fg'' at e, and $y'o_1$ intersects $q'o_2$ on the fixed vertical $f'g'$ at e'. That these must be so is evident from a consideration of what occurs during a supposed revolution of the tangent t_1t_1', to the position xy'.

Now having determined the moment bk over the pier, kb_6 and kb_9' are the true closing lines of the moment polygons c and c'. Call these closing lines k, then the ordinates of the type kc will represent the bending moments at different points of the girder. The points of the contra flexure are at the points where the closing lines intersect the polygons c and c'. The directions of the closing lines will permit at once the determination of the resistances at the piers and the shearing stresses at any point.

The particular difference between the construction in case of constant and of variable moment of inertia, is seen to be in the positions of the center verticals positive and negative, and the right and left verticals.

The small change in their position due to the variation in moment of inertia, is the justification of the remarks previously made respecting the close approximation of the two cases.

It is seen that the process here developed can be applied with equal facility to a girder with any number of spans. Also if the moment of inertia varies continuously instead of suddenly, as assumed in Fig. 13, the panels can be taken short enough to approximate with any required degree of accuracy to this case.

THE THEOREM OF THREE MOMENTS.

The preceding construction has been in reality founded on the theorem of three moments, but when the equation expressing that theorem is written in the usual manner, the relationship is difficult to see. Indeed the equation as given by Weyrauch* for the girder having a variable moment of inertia, is of so complicated a nature that it may be thought hopeless to attempt to associate mechanical ideas with the terms of the equation, in any clearly defined relationship. We propose to derive and express the equation in a novel manner, which will at once be easy to understand, and not difficult of interpretation in connection with the preceding construction.

Let us assume the general equation of deflections in the form.

$$D=\Sigma(Mx\div EI), \text{ or } D.EI_0=\Sigma(Mix) \qquad (7)$$

in which I is the variable moment of inertia, I_0 some particular value of I assumed as the standard of comparison, $i=I_0\div I$, and x is measured horizontally from the point as origin, where the deflection D is taken to the point of application of the actual bending moment M. The quantity Mi is called the effective bending moment, and the deflection D is measured from the tangent of the deflection curve at the point to which the summation is extended from the origin.

Now consider two contiguous spans of a continuous girder of several spans, and let acb denote the piers, c being the intermediate pier. Let the span $ac=l$ and $bc=l'$. Take the origin at a and extend the summation to c, calling the deflection at a, D_a. When the origin is at b and the summation extends to c, let the deflection be D_b. Let also y_a, y_b and y_c be the heights of a, b and c respectively above some datum level. Then, as may be readily seen,

$$D_a = y_a - y_c - lt_c\ ;$$
$$D_b = y_b - y_c - l't_c',$$

if t_c is the tangent of the acute angle at c on the side towards a between the tangent line of the deflection curve at c and the horizontal, and t_c' is the tangent of the corresponding acute angle on the side of c towards b.

Now if we consider equation (7) to refer to the span l, the moment M may be taken to be made up of three parts, viz:—M_0 caused by the weights on the girder, M_1 dependent on the moment M_c at c, and M_2 dependent on the moment M_a at a. The moments in the span l' may be resolved in a similar manner. We may then write the equations of deflections in the two spans when the summation extends over each entire span as follows:

$$EI_0(y_a-y_c-lt_c)=\Sigma_c^a(M_0ix)-\Sigma_c^a(M_1ix)$$
$$-\Sigma_c^a(M_2ix) \quad . \ . \ . \ . \ . \quad (8)$$

$$EI_0(y_b-y_c-l't_c')=\Sigma_c^b(M_0'i'x')$$
$$-\Sigma_c^b(M_1'i'x')-\Sigma_c^b(M_2'i'x') \quad (9)$$

in which x is measured from a, and x' from b towards c. Now if the girder is originally straight, $t_c = -t_c'$, hence we can combine these two equations so as to eliminate t_c and t_c', and the resulting equation will express a relationship between the heights of the piers, the bending moments (positive and negative), their points of application and the moments of inertia; of which quantities the negative bending moments are alone unknown. The equation we should thus obtain would be the general equation of which the ordinary expression of the

* Allgemeine Theorie und Berechnung der Continuirlichen und Einfachen Trager. Jakob I. Weyrauch. Leipzig 1873.

theorem of three moments is a particular case. Before we write this general equation it is desirable to introduce certain modifications of form which do not diminish its generality. Suppose that

$$\bar{x}_1 \Sigma_c^a (M_1 i) = \Sigma_c^a (M_1 i x)$$

then is $\bar{x}_1$ the distance from a to the center of gravity of the negative effective moment area next to c. As was shown in connection with Fig. 13, the position of this center of gravity is independent of the magnitude of M_1 or M_c and may be found from the equation,

$$\bar{x}_1 = \frac{\int_c^a i x^2 dx}{\int_c^a i x dx} \quad . \quad . \quad . \quad . \quad (10)$$

for M_1 is proportional to x. Similarly it may be shown that

$$\bar{x}_2 = \frac{\int_c^a i(l-x) x dx}{\int_c^a i(lx) dx} \quad . \quad . \quad (11)$$

is the distance of the center of gravity of the negative effective moment area next to a.

Again, suppose that

$$i_1 \Sigma_c^a (M_1) = \Sigma_c^a (Mi)$$

then is i_1 an average value of i for the negative effective moment area next to c, which is likewise independent of the magnitude of M_1, as appears from reasoning like that just adduced respecting $\bar{x}_1$. Hence i_1 may be found from the equation

$$i_1 = \frac{\int_c^a i x dx}{\int_c^a x dx} \quad . \quad . \quad . \quad (12)$$

Similarly it may be shown that

$$i_2 = \frac{\int_c^a i(l-x) dx}{\int_c^a (l-x) dx} \quad . \quad . \quad (13)$$

in which i_2 is the average value of i for the negative effective moment area next to a.

The integrals in equations (10), (11), (12), (13), and in others like them referring to the span l', which contain i must be integrated differently, in case i is discontinuous, as it usually is in a truss, from the case where i varies continuously. When i is discontinuous the integral extending from c to a must be separated into the sum of several integrals, each of which must extend over that portion of the span l in which i varies continuously.

Further more we have

$$\Sigma_c^a (M_1) = \tfrac{1}{2} M_c l \quad . \quad . \quad . \quad (14)$$

since each member of this equation represents the negative actual moment area next to c in the span l.

Similarly, we have the equations

$$\Sigma_c^a (M_2) = \tfrac{1}{2} M_a l \text{ , } \Sigma_c^b (M_1') = \tfrac{1}{2} M_c' l',$$
$$\Sigma_c^b (M_2' l') = \tfrac{1}{2} M_b l').$$

If there is no constraint at the pier then must $M_c = M_c'$.

Now making the substitutions in equations (8) and (9), which have been indicated in the developments just completed, and then eliminating t_c and t_c',

$$EI_0 \left\{ \frac{y_a - y_c}{l} + \frac{y_b - y_c}{l'} \right\} - \frac{\bar{x}_0 i_0}{l'} \Sigma_c^a (M_0) - \frac{\bar{x}_0' i_0'}{l'} \Sigma_c^b (M_0') = \tfrac{1}{2} [M_a \bar{x}_2 i_2 + M_c (\bar{x}_1 i_1 + x_1' i_1') + M_b \bar{x}_2' i_2'] \quad . \quad . \quad . \quad (15)$$

in which $\bar{x}_0$ is the distance from a of the center of gravity of the positive effective moment area due to the weights in the span l, and $\bar{x}_0'$ is a similar distance from b in the span l', while i_0 and i_0' are average values of i for these areas derived from the equations in each span,

$$i_0 = \Sigma(M_0 i) \div \Sigma(M_0).$$

It may frequently be best to leave the expressions containing the positive moments in their original form as expressed in equations (8) and (9).

Let us now derive from equation (15), the ordinary equation expressing the theorem of three moments, for a girder having a constant cross section. In this case $i=1$, and we wish to find the value of the term $\Sigma(M_0 x)$ in each span. Let M_0 be caused by several weights P applied at distances z from a, then the moment due to a single weight P at its point of application is

$$M_z = Pz(l-z) \div l,$$

which may be taken as the height of the triangular moment area whose base is l which is caused by P. This triangle whose area is $\frac{1}{2}M_z l$ is the component of $\Sigma(M_0)$ due to P and can be applied as a concentrated bending moment at its center of gravity at a distance x from a.

Now $x=\frac{1}{3}(l+z)$, and taking all the weights P at once

$$\Sigma_c^a(M_0 x)=\frac{1}{6}\Sigma_c^a[P(l^2-z^2)z].$$

Also in equation (15) we have in this case

$$\bar{x}_1=\frac{1}{3}l,\ \bar{x}_2=\frac{2}{3}l,\ \bar{x}_1'=\frac{1}{3}l',\ \bar{x}_2'=\frac{2}{3}l'$$

$$\therefore\ 6EI\left\{\frac{y_a-y_c}{l}+\frac{y_b-y_c}{l'}\right\}$$

$$-\frac{1}{l}\Sigma_c^a[P(l^2-z^2)z]-\frac{1}{l'}\Sigma_c^b[P'(l'^2-z'^2)z']$$

$$=M_a l+2M_c\ (l+l')+M_b l' \quad . \quad (16)$$

Equation (16) then expresses the theorem of three moments for a girder having a constant moment of inertia I, and deflected by weights applied in the span l at distances z from a, and also by weights in the span l' at distances z' from b.

Let us also take the particular case of equation (15) when the moment of inertia is invariable and the piers on a level; then $i=1$, and if we let A_0 and A_0' be the positive moment areas due to the weights we have

$$6\left\{\frac{1}{l}A_0\bar{x}_0+\frac{1}{l'}A_0'\bar{x}'_0\right\}=$$

$$M_a l+2M_c\ (l+l')+M_b l' \quad . \quad . \quad (17)$$

This form of the equation of three moments was first given by Greene.* The advantage to be derived in discussing this theorem in terms of the bending moments, instead of the applied weights is evident both in the analytical and the graphical treatment. The extreme complexity of the ordinary formulae arises from their being obtained in terms of the weights.

In order to complete the analytic solution of the continuous girder in the general case of equation (15), it is only necessary to use the well known equations,

$$M=M_c+S_c z_0-\Sigma_c^o(Pz_0) \quad . \quad . \quad (18)$$

$$S_c=\frac{1}{l}\ [M_a-M_c+\Sigma_c^a(Pz)] \quad . \quad . \quad (19)$$

$$S_c'=\frac{1}{l'}\ [M_b-M_c+\Sigma_c^b\ (Pz')\ ] \quad . \quad (20)$$

* Graphical Method for the Analysis of Bridge Trusses. Chas. E. Greene. Published by D. Van Nostrand. New York, 1875.

$$R_c=S_c+S_c' \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$S=S_c-\Sigma_c^o(P) \quad . \quad . \quad . \quad . \quad . \quad (22)$$

In (18) M is the bending moment at any point O in the span l, S_c is the shear at c due to the weights in the span l, and z_0 is the distance from O towards c of the applied forces P and S_c in the segment O_c.

Equation (19) is derived from (18) by taking O at a, and (20) is obtained similarly in the span l'. R_c is the reaction of the pier at c. S is the shear at O in the span l. These equations also complete the solution of the cases treated in (16) and (17).

THE FLEXIBLE ARCH RIB AND STIFFENING TRUSS.

Whenever the moment of inertia of an arch rib is so small, that it cannot afford a sufficient resistance to hold in equilibrium the bending moments due to the weights, it may be termed a flexible rib.

It must have a sufficient cross section to resist the compression directly along the rib, but needs to be stiffened by a truss, which will most conveniently be made straight and horizontal. The rib may have a large number of hinge joints which must be rigidly connected with the truss, usually by vertical parts. It is then perfectly flexible.

If, however, the rib be continuous without joints, or have blockwork joints, it may nevertheless be treated as if perfectly flexible, as this supposition will be approximately correct and on the side of safety, for the bending moments induced in the truss will be very nearly as great as if the rib were perfectly flexible, in case the same weight would cause a much greater deflection in the rib than in the truss. It will be sufficient to describe the construction for the flexible rib without a figure, as the construction can afford no difficulties after the constructions already given have been mastered.

Lay off on some assumed scale the applied weights as a load line, and let us call this vertical load line ww'. Divide the span into some convenient number of equal parts by verticals, which will divide the curve a of the rib into segments. From some point b as a pole draw a pencil of rays parallel to the segments of a, and across this pencil draw a vertical line uu', at such a distance from b that the distance uu' between the extreme rays of the pencil is equal to ww'. Then the segments of uu' made by the rays of the pencil are the loads which the arch rib would sustain in virtue of its being an equilibrium polygon, and they would induce no bending moments if applied to the arch. The actual loads in general are differently distributed. By Prop. VI the bending moments induced in the truss are those due to the difference of the weight actually resting on the arch at each point, and the weight of the same total amount distributed as shown by the segments of the line uu'.

Now lay off a load line vv' made up of weights which are these differences of the segments of uu' and ww', taking care to observe the signs of these differences. The algebraic sum of all the weights vv' vanishes when the weights which rest on the piers are included, as appears from inspection of the construction in the lower part of Fig. 10. The construction above described will differ from that in Fig. 10 in one particular. The rib will not in general be parabolic, and the loads which it will sustain in virtue of its being an equilibrium polygon will not be uniformly distributed, hence the differences which are found as the loading of the stiffening truss do not generally constitute a uniformly distributed load.

The horizontal thrust of the arch is the distance of uu' from b measured on the scale on which the loads are laid off, and the thrust along the arch at any point is length of the corresponding ray of the pencil between b and uu'. These thrusts depend only on the total weight sustained, while the bending moments of the stiffening truss depend on the manner in which it is distributed, and on the shape of the arch.

Having determined thus the weights applied to the stiffening truss, it is to be treated as a straight girder, by methods previously explained according to the way in which it is supported at the piers.

The effect of variations of temperature is to make the crown of the arch rise and fall by an amount which can be readily determined with sufficient exactness, (see Rankine's Applied Mechanics Art. 169). This rise or fall of the arch produces bending moments in the stiffening truss, which is fastened to the tops of the piers, which are the same as would be produced by a positive or negative loading, causing the same deflection at the center and distributed in the same manner as the segments of uu': for it is such a distribution of loads or pressures which the rib can sustain or produce. A similar set of moments can be induced in the stiffening truss by lengthening the posts between the rib and truss.

When this deflection and the value of EI in the truss are known, these moments can be at once constructed by methods like those already employed. A judicious amount of cambering of this kind is of great use in giving the structure what may be called "initial stiffness." The St. Louis Arch is wanting in initial stiffness to such an extent that the weight of a single person is sufficient to cause a considerable tremor over an entire span. This would not have been possible had the bridge consisted of an arch stiffened by a truss which was anchored to the piers in such a state of bending tension as to exert considerable pressure upon the arch. This tension of the truss would be relieved to some extent during the passage of a live load.

The arch rib with stiffening truss, is a form of which many wooden bridges were erected in Pennsylvania in the earlier days of American railroad building, but its theory does not seem to have been well understood by all who erected them, as the stiffening truss was itself usually made strong enough to bear the applied weights, and the arch was added for additional security and stiffness, while instead of anchoring the truss to the piers and causing it to exert a pressure on the arch, a far different distribution of pressures was adopted. Quite a number of bridges of this pattern are figured by Haupt* from the designs of the builders, but most of them show by the manner of bracing near the piers that the engineers who designed them did not know how to take advantage of the peculiarities of this combination. This further appears from the fact, that, the trussing is not usually continuous.

* Theory of Bridge Construction. Herman Haupt, A.M. New York. 1853.

A good example, however, of this combination constructed on correct principles is very fully described by Haupt on pages 169 *et seq.* of his treatise. It is a wooden bridge over the Susquehanna River, $5\frac{1}{2}$ miles from Harrisburg on the Pennsylvania Railroad, and was designed by Haupt. It consists of twenty-three spans of 160 feet each from center to center of piers. The arches have each a span of $149\frac{1}{4}$ feet and a rise of 20 ft. 10 in., and are stiffened by a Howe Truss which is continuous over the piers and fastened to them. It was erected in 1849. Those parts which were protected from the weather have remained intact, while other parts have been replaced, as often as they have decayed, by pieces of the original dimensions. This bridge, though not designed for the heavy traffic of these days, still stands after twenty-eight years of use, a proof of the real value of this kind of combination in bridge building.

STOPPING AND STARTING RAILROAD TRAINS.

By Prof. E. W. HYDE, C.E., University of Cincinnati.

Written for Van Nostrand's Magazine.

It is proposed in this paper to compare the expense of stopping a train moving at a given speed, and then bringing it up again to that speed, with that of maintaining the given velocity unchanged over the distance between the point at which steam is shut off, for stopping the train, and the point at which the original velocity is again attained.

The main thing to be considered is of course the amount of mechanical work done in each of the two cases.

To determine this it will be necessary to investigate the relations existing between time, space, and velocity for a moving train.

The resistances encountered by the train are in part constant, and in part dependent on the velocity. Several empirical formulæ have been given expressing more or less accurately the amount of these resistances. Mr. Scott Russell has found for the train, exclusive of the locomotive, resistance in lbs. $= \left(6+\frac{V}{3}\right)T+\frac{V^2A}{400}$, in which T = weight of train in tons, V = velocity in miles per hour, and A = area of frontage in square feet. Mr. Wyndham Harding gives for the same, resistance $= \left(6+\frac{V}{15}\right)T+\frac{V^2B}{50000}$, in which V and T are as before, and B is the volume of the train in cubic feet.

Mr. Gooch gives

$$\text{resistance} = 6T\left(1+\frac{V-10}{20}\right):$$

and Mr. D. R. Clark

$$\text{resistance} = 6T\left(1+\frac{V^2}{1440}\right).$$

These formulæ may be found in Rankine's Civil Engineering. Rankine also gives a formula for the locomotive and train as follows:

$$\text{total resistance} = R = (T+E)\left(8+\frac{V^2}{180}\right),$$

E being the weight of the engine in tons.

All these formulæ apply to level track only, and in what follows we shall always suppose a level, straight track, and no wind blowing so as to have an appreciable component in the direction of the road.

We may write in general

$$R=F+\mu_1 v+\mu_2 v^2 \quad . \quad . \quad (1)$$

which will reduce to either of the above formulæ by giving proper values to F, μ_1, and μ_2. Hence if we call P_1 the accelerating force exerted by the locomotive, or the retarding force of the brakes, as the case may be, and M the entire mass of the train, we shall have

$$M\frac{d^2s}{dt^2}=M\frac{dv}{dt}=P_1\pm F\pm\mu_1 v\pm\mu_2 v^2 \quad . \quad (2)$$

We will first use the lower signs, making $P=P_1-F$.

$$\therefore\ t=M\int_0^v\frac{dv}{P-\mu_1 v-\mu_2 v^2},$$

$$=\frac{M}{a}\log.\frac{2P-v(\mu_1-a)}{2P-v(\mu_1+a)} \qquad (3)$$

in which log. = Naperian logarithm, and

$$a=\sqrt{\mu_1^2+4\mu_2 P}.$$

$\therefore \ \varepsilon^{\frac{at}{M}} = \frac{2P - v(\mu_1 - a)}{2P - v(\mu_1 + a)} + \varepsilon^{mt}$, if we place $\frac{a}{M} = m$; whence solving for v, we have

$$v = \frac{ds}{dt} = \frac{2P(\varepsilon^{mt} - 1)}{(\mu_1 + a)\varepsilon^{mt} + a - \mu_1} \quad . \quad . \quad (4)$$

$$\therefore \quad s = 2P \int_o^t \frac{(\varepsilon^{mt} - 1)\, dt}{(a + \mu_1)\varepsilon^{mt} + (a - \mu_1)} \quad (5)$$

Let $\varepsilon^{mt} = x$; $\therefore t = \frac{1}{m}$ log. x, and $\frac{dt}{dx} = \frac{1}{m} \cdot \frac{1}{x}$. Substituting in (5)) we have

$$s = \frac{2P}{m} \int_1^{\varepsilon^{mt}} \frac{(x-1)\,dx}{[(a+\mu_1)x + a - \mu_1]x}$$

$$\therefore s = \frac{2PM}{a} \left\{ \frac{1}{a+\mu_1} \log.[(a+\mu_1)x + a - \mu_1] + \frac{1}{a-\mu_1} \log. \frac{(a+\mu_1)x + a - \mu_1}{x} \right\}_1^{\varepsilon^{mt}}$$

Whence by introduction of limits and reduction

$$s = \frac{M}{\mu_2} \log. \frac{(a+\mu_1)\varepsilon^{\frac{at}{M}} + a - \mu_1}{2a} - \frac{2Pt}{a - \mu_1} \quad (6)$$

Thus we have in equation (3) the relation between t and v, and in equation (6) that between s and t, for the case in which the velocity is accelerated from o up to v. If we substitute the value of t from (3) in (6), we obtain a relation between s and v as follows,

$$s = \frac{M}{\mu_2} \log \frac{2P}{2P - v(a+\mu_1)} - \frac{2PM}{a(a-\mu_1)} \log \frac{2P - v(\mu_1 - a)}{2P - v(\mu_1 + a)} \quad . \quad (7)$$

For the case in which the train is retarded, let $P' = P_1 + F$, and

$$b = \sqrt{\mu_1^2 - 4\mu_2 P'},$$

then changing the signs of μ_1 and μ_2 in the equations (3) (6) and (7) already obtained, we shall have

$$t' = \frac{M}{b} \log \frac{2P' + v(\mu_1 + b)}{2P' + v(\mu_1 - b)} \quad . \quad . \quad (8)$$

$$s' = \frac{M}{\mu_2} \log. \frac{2b}{(b - \mu_1)\varepsilon^{\frac{bt'}{M}} + b + \mu_1} - \frac{2P't'}{b + \mu_1} \quad (9)$$

$$s' = \frac{M}{\mu_2} \log. \frac{2P + v(\mu_1 - b)}{2P'} - \frac{2P'M}{b(b+\mu_1)} \log. \frac{2P' + v(\mu_1 + b)}{2P' + v(\mu_1 - b)} \quad . \quad . \quad (10)$$

In this case, however, if $P' = \frac{\mu_1^2}{4\mu_2}$, then $b = o$, and the value of t' becomes $\frac{o}{o}$. By differentiation the true value in this case is found to be,

$$t'_{b=o} = \frac{2Mv}{2P' + \mu_1 v} = \frac{4Mv\mu_2}{\mu_1^2 + 2v\mu_1\mu_2}; \quad . \quad (11)$$

and in the same case

$$s'_{b=o} = \frac{M}{\mu_2} \log. \frac{\mu_1 + 2v\mu_2}{\mu_1} - \frac{\mu_1}{2\mu_2} t' \quad . \quad (12)$$

If $P' > \frac{\mu_1^2}{4\mu_2}$, b becomes imaginary, and eq. (2) must be integrated differently.

We have in this case, placing

$$\sqrt{4\mu_2 P' - \mu_1^2} = c,$$

$$t' = \frac{2M}{c} \tan.^{-1} \frac{cv}{2P' + \mu_1 v} \quad . \quad (13)$$

$$\text{Therefore } s = 2P' \int_o^t \frac{\tan. \frac{ct}{2M} \cdot dt}{c - \mu_1 \tan. \frac{ct}{2M}},$$

and by integration,

$$s' = \frac{M}{\mu_2} \log. \frac{c \sec. \frac{ct}{2M}}{c - \mu_1 \tan. \frac{ct}{2M}} - \frac{\mu_1 t}{2\mu_2}; \quad . \quad (14)$$

or introducing value of t from (13),

$$s' = \frac{M}{2\mu_2} \log. \frac{P' + \mu_1 v + \mu_2 v^2}{P} - \frac{M\mu_1}{c\mu_2} \tan.^{-1} \frac{cv}{2P' + \mu_1 v} \quad . \quad (15)$$

Let us expand the right hand member of (13) by the formula $\tan.^{-1} y = y - \frac{1}{3}y^3 + \frac{1}{5}y^5 - \&c.$,

$$\therefore t' = \frac{2Mv}{2P' + \mu_1 v} - \frac{2Mc^2v^3}{3(2P' + \mu_1 v)^3} + \frac{2Mc^4v^5}{5(2P' + \mu_1 v)^5}, \ \&c.$$

In this if $c = o$ all the terms of the 2nd member disappear but the 1st, and we have eq. (11) again. Also if P' be infinite all the terms disappear; hence each term after the first must have a maximum value for some value of P'. This value of P' is easily found by differentiation, and for the second term of the series it is

$$\frac{\mu_1(3\mu_1+2\mu_2 v)}{8\mu_2},$$

and the corresponding value of the second term is

$$\frac{64M\mu_2{}^3v^3}{81(\mu_1{}^2+2\mu_1\mu_2 v)^2}.$$

This is generally a very small quantity,—in a case we shall presently discuss less than $\frac{1}{4}$ of a second,—and the succeeding terms are much smaller, so that the first term alone gives a very close approximation to the true value of t', and we may consequently use with sufficient accuracy

$$t'=\frac{2\,Mv}{2\,P'+\mu_1 v} \quad . \quad . \quad . \quad (16)$$

whenever we have $P'>\frac{\mu_1{}^2}{4\mu_2}$.

In Mr. Gooch's formula $\mu_2=0$; therefore we have from (3),

$$t=\frac{M}{\mu_1}\log.\frac{P}{P-\mu_1 v} \quad . \quad . \quad (17)$$

whence solving for $v\left(=\frac{ds}{dt}\right)$, and integrating

$$s=\frac{PM}{\mu_1{}^2}\left(\varepsilon^{-\frac{\mu_1 t}{M}}-1\right)+\frac{Pt}{\mu_1} \quad . \quad . \quad . \quad (18)$$

or by (17),

$$s=\frac{Pt-Mv}{\mu_1} \quad . \quad . \quad . \quad . \quad (19)$$

Eqs. (17), (18) and (19) are for the case in which the train is accelerated. For the case of retardation, change the sign of μ_1 in (17), (18) and (19), and substitute P' for P, t' for t, and s' for s,

$$\therefore\ t'=\frac{M}{\mu_1}\log.\frac{P'+\mu_1 v}{P'} \quad . \quad . \quad (20)$$

and

$$s'=\frac{P'M}{\mu_1{}^2}\left(\varepsilon^{\frac{\mu_1 t'}{M}}-1\right)-\frac{P't'}{\mu_1} \quad . \quad (21)$$

or by (20),

$$s'=\frac{Mv-P't'}{\mu_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

In Mr. Clark's formula $\mu_1=0$, hence from eqs. (3), (6), (7), (13), (14) and (15),

$$t=\frac{M}{2\sqrt{\mu_2 P}}\log.\frac{\sqrt{P}+v\sqrt{\mu_2}}{\sqrt{P}-v\sqrt{\mu_2}} \quad (23)$$

$$s=\frac{M}{2\mu_2}\log.\frac{(\varepsilon^{nt}+1)^2}{4\,\varepsilon^{nt}} \quad . \quad . \quad . \quad (24)$$

in which $n=\frac{2\sqrt{\mu_2 P}}{M}$

$$s=\frac{M}{2\mu_2}\log.\frac{P}{P-\mu_2 v^2} \quad . \quad . \quad . \quad (25)$$

$$t'=\frac{M}{\sqrt{\mu_2 P}}\tan.^{-1} v\sqrt{\frac{\mu_2}{P}} \quad . \quad . \quad (26)$$

$$s'=\frac{M}{\mu_2}\log.\sec.\frac{t'\sqrt{\mu_2 P}}{M} \quad . \quad (27)$$

and

$$s'=\frac{M}{2\mu_2}\log.\frac{P+\mu_2 v^2}{P} \quad . \quad . \quad (28)$$

We are now prepared to discuss a particular case. We will take a train composed of engine, tender, baggage car, and six Pullman cars.

Weight of engine$=E'=70000$ lbs.

Weight of train$=T'=541600$ lbs.

Total weight$=W=611600$ lbs.

$$M=\frac{W}{g}=\frac{611600}{32.2}=18993.8.$$

Let us assume that $v=60$ ft. per sec., that is nearly forty-one miles per hour.

We will first make the computation by Scott Russell's formula.

We will allow in this case, in addition to the 6 lbs. per ton for friction for the whole train, 7 lbs. per ton of the weight of the engine + 1 lb. per ton of the train exclusive of the engine for the internal friction of the same, *i.e.* $F=\frac{7T'+13E'}{2240}$

$$\therefore\ F=\frac{7\times541600+13\times70000}{2240}=2098.75$$

μ_1 is that part of the resistance which varies as the 1st power of the velocity taken at a velocity of 1 ft. per second, therefore from the formula

$$\mu_1=\frac{W}{3\times2240}\cdot\frac{15}{22}=\frac{W}{9856}=62.054.$$

μ_2 is the resistance of the air at a velocity of one foot per sec.

$$\therefore\quad \mu_2=\frac{A}{400}\cdot\left(\frac{15}{22}\right)^2$$

If we assume $A=100$ sq. ft. we have

$$\mu_2=\tfrac{1}{4}\left(\tfrac{15}{22}\right)^2=0.1162.$$

Hence the force required to move the train at a constant velocity of 60 ft. is

$$R=F+\mu_1 v+\mu_2 v^2=2098.75+3723.22+418.32=6240.29.$$

If we should start from rest with a force $P_1=R$, we should attain a velocity of 60 ft. only after an infinite length of time, as may be seen by introducing this value of P_1 in eq. (3), first reducing it as follows:

$$t=\frac{M}{a}\log.\frac{2P-\mu_1v+av}{2P-\mu_1v-av}$$

$$=\frac{M}{a}\log.\frac{2P-\mu_1v+av}{2P-\mu_1v-av}\cdot\frac{2P-\mu_1v+av}{2P-\mu_1v+av}$$

$$=\frac{M}{a}\log.\frac{(2P-\mu_1v+av)^2}{4P(P-\mu_1v-\mu_2v)^2}$$

$$=\frac{M}{a}\log.\frac{(2P-\mu_1v+av)^2}{4P(P_1-F-\mu_1v-\mu_2v^2)}.$$

It is evident that if $P_1=R$ be substituted in this equation, we shall have

$$t=\frac{M}{a}\log.\infty=\infty.$$

Hence we must assume $P_1>R$ in order to attain the desired velocity within a finite time. Let us take it first at 7098.75 lbs., so that $P=P_1-F=5000$ lbs.; then by eq. (3), $t=471.4$ sec. $=7$ min. 51.4 sec., and by eq. (6) or (7),

$$s=18084.4 \text{ ft.}=3 \text{ miles } 2244.4 \text{ ft.}$$

Let us call the work done by the resultant force acting on the train L_1, that actually done by the locomotive in passing over the space s L_2, and that which would be done by the locomotive in passing over the same space at a constant velocity of 60 ft. L_3, then we have:

$$L_1=\frac{Mv^2}{2}=\frac{18993.8\times3600}{2}=34188840 \text{ ft. lbs.}$$

$$L_2=P_1s=7098.75\times18084.4=128377316 \text{ ft. lbs.}$$

$$L_3=R\,s=6240.29\times18084.4=112851914 \text{ ft. lbs.}$$

$\frac{L_2}{L_1}=3.75+$, so that the work done in overcoming the inertia is only a little more than one-quarter part of the work actually performed by the engine. The difference between L_2 and L_3 represents the extra work done in getting up speed over and and above what would be done in going over the same space *at* speed. This is

$$L_2-L_3=(P_1-R)s=15525402 \text{ ft. lbs.}$$

There is a gain, however, to offset this loss, for the space passed over by the train from the point at which steam is shut off to that at which the train comes to rest is traveled without any work being done by the engine, and thus work is gained equivalent to the product of R by this distance. If we divide L_2-L_3 by R we shall obtain the distance which must be passed over in stopping the train, in order that the gain of work may just balance the loss, viz.:

$$\frac{L_2-L_3}{R}=\frac{15525402}{6240.29}=2488 \text{ ft.}$$

Hence we see that if steam is shut off at a distance of about 2500 ft. from the station there will be *no loss whatever* of mechanical work in stopping the train and getting up speed again. If the train is stopped in *less* space there will be some loss of work, if in greater there will be an actual *gain*. There will also be a small loss due to the wear and tear of brakes and the loss of time, the amount of which we shall consider hereafter. Let us next assume that the engine exerts a greater force so as to reach the velocity of sixty feet in less time, and see what the result will be.

Let $P_1=7498.75$ lbs., and, therefore,

$$P=P_1-F=5400 \text{ lbs.}$$

Then by Eqs. (3) and (6)

$$t'=392.6 \text{ sec.}=6 \text{ min. } 32.6 \text{ sec.}$$

$$s'=14533.4 \text{ ft.}=2 \text{ miles } 3973.4 \text{ ft.}$$

$$\frac{L'_2-L'_3}{R}=\frac{18289672}{6240.29}=2931 \text{ ft.}$$

Thus we see that as the engine exerts more force, there is a greater loss of mechanical work, to compensate for which it would be necessary to reduce speed more gradually in stopping. It appears, then, that for economy we must "make haste slowly" in this as in other matters.

Moreover, the gain of time is but trifling, being only nineteen seconds in reaching any given point, if we suppose the train in each case to move on with a uniform velocity of sixty feet, as soon as it has attained to that speed.

We will next apply Mr. Clark's formula to the same case. Clark says that for a road badly laid, or out of repair, forty per cent. should be added to the results obtained by his formula. As his experiments were made in England, where the roads are in general better made and kept than in this country, it would seem that at least twenty per cent. should be added to obtain a fair result for the average case in this country, which would give

$$R=\frac{W}{2240}\cdot\frac{6}{5}\left(8+\frac{V^2}{180}\right).$$

Whence $F=\frac{3\,W}{700}=2621$ lbs. and

$$\mu_2=\frac{6\,W}{5\times180\times2240}\left(\frac{15}{22}\right)^2=0.84605.$$

$\therefore\ F+\mu_2v^2=R'=2621+3046=5667$ lbs.

It will be seen that this formula, even with the twenty per cent. which we have added, gives a resulting value of R considerably smaller than that of Russell. Let us first take $P=3600$, so that $P_1=P+F=6221$ lbs. Then from formulas (23) and (25)

$t=546.4$ sec. $=9$ min. 6.4 sec. and
$s=21004$ ft. $=3$ miles 5164 ft.

$$\therefore\frac{L''_2-L''_3}{R'}=2053 \text{ feet.}$$

In this case we have been longer in getting up speed, and find, consequently, that we can stop more quickly without loss of work.

Since we can solve equation (25) for P, we can find the force which must be exerted by the engine in order to get up speed within a given distance. For the sake of comparing the two formulæ,—those of Russell and Clark,—let us assume
$s=18084$ ft. as was found in the first case considered. Then we find

$P=3806$, $\therefore P_1=6427$,
$t=483.4$ sec. $=8$ min. 3.4 sec.,

and $\frac{L_2'''-L_3'''}{R'}=2425$ ft., so that this formula gives the time twelve seconds greater, and the distance to be passed over in stopping is sixty-three feet less than that of Russell.

If we use Clark's formula without adding twenty per cent., we find $R=4722.84$, and when $s=18084$

$\frac{\overset{\text{IV}}{L}_2-\overset{\text{IV}}{L}_3}{R}=3434$ ft., so that as the resistance become less it is necessary to pass over more space in stopping in order to have no loss of work. We can see this at once from general considerations, for suppose that there were *no* resistances, then the work done in getting up speed would be merely that of overcoming the inertia, *i.e.*

$L_2=L_1=\frac{m\,v^2}{2}=34188840$ ft. lbs., while we should have $L_3=0$, $R=0$ and

$$\therefore\ \frac{L_2-L_3}{R}=\infty.$$

Thus there would *always* be a loss of work in stopping.

The results obtained by the other formulæ do not differ very essentially from those already given, though both of them give values of R at high velocities less than that of Scott Russell.

We will next take a freight train weighing 966000 lbs. in all, of which 75000 lbs. is the weight of the locomotive,

$$\therefore\ M=\frac{W}{g}=\frac{966000}{32.2}=30000.$$

Using Russell's formula and proceeding as before we find :

$\mu_1=98.193$ and $\mu_2=0.08135$.

Let $v=22$ ft. per sec. $=15$ miles per hour.

$\therefore\ F+\mu_1v+\mu_2v^2=3219.6+2160.2+39.4$
$=5419.2$.

Suppose that $P=2800$, $\therefore P_1=6019.6$; then by equations (3) and (7)

$t=460$ sec. $=7$ min. 40 sec.
$s=6343$ ft. $=1$ mile 1063 ft.

$\therefore\ \overset{\text{V}}{L}_2=38181114$ ft. lbs., $\overset{\text{V}}{L}_3=34373032$

and $\frac{\overset{\text{V}}{L}_2-\overset{\text{V}}{L}_3}{R}=\frac{3808082}{5419.2}=703$ ft.; so that in this case it is only necessary to shut off steam at about 700 ft. from the station in order to avoid loss of work.

We will now consider the relations of force, time and space in bringing the train to rest. Taking the express train first treated, with a velocity sixty feet per second, we find by Russell's formula when

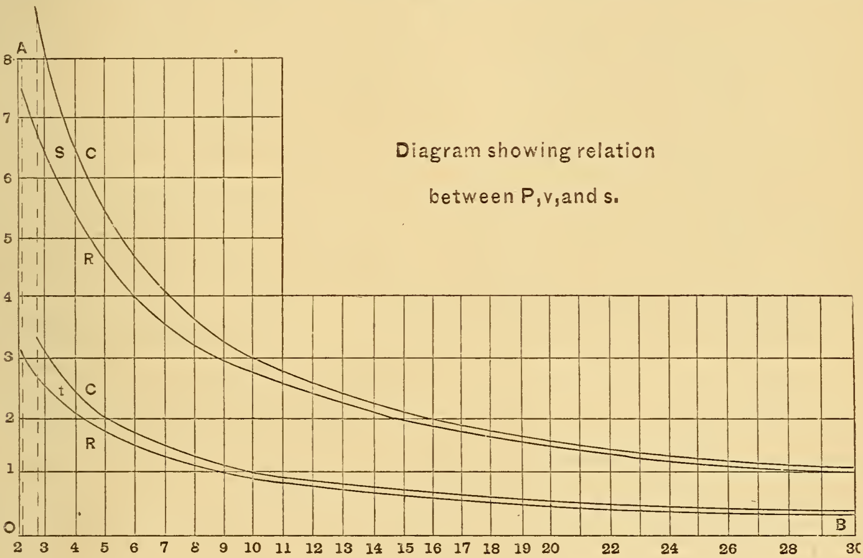
$P=F=2098.75$ lbs., $t=305$ sec., and $s=7524$ ft.,
$P=3000$ lbs., $t=242$ sec., and $s=6220$ ft.,
$P=4000$ " $t=198$ " and $s=5239$ ft.,
$P=5000$ " $t=168$ " and $s=4529$ ft.,
$P=6000$ " $t=146$ " and $s=3991$ ft.,

$P=\frac{\mu_1^2}{4\mu_2}=8284.5$ lbs., $t=112$ sec.,
and $s=3143$

P=10000 lbs., t=96 sec., and s=2701 ft..
P=15000 lbs., t=67 sec., and s=1939 ft.,
P=20000 lbs., t=52 sec., and s=1489 ft.,
P=30000 lbs., t=36 sec.,
and s=1000 ft. nearly.

Thus according to this formula the train would come to rest by the operation of ordinary resistances without using the brakes in about five minutes, passing over in that time a distance of about 7500 feet. Since Clark's formula makes the resistances somewhat less, it follows that it would show a greater brake-force to be required to stop the train in a given time or distance.

According to this formula, when
P=F=2621 lb, t=332 sec., and s=8655 ft.
P=3600 lbs., t=256 sec., and s=6882 ft.,
P=4900 lbs., t=197 sec., and s=5426 ft.,
P=6400 lbs., t=156 sec., and s=4370 ft.,
P=8100 lbs., t=126 sec., and s=3583 ft.,
P=10000 lbs., t=104 sec., and s=2984 ft.,
P=20000 lbs., t=57 sec., and s=1591 ft.,
P=30000 lbs., t=38 sec., and s=1085 ft.



The accompanying diagram will show clearly the relations between these results. The numbers along the horizontal line O B give values of P in thousands of lbs., those along the vertical O A give t in hundreds of seconds, and s in thousands of feet, assuming that v=60.

The lower pair of curves, marked t, are time curves, the upper of the two, marked C, being constructed by Clark's formula, and the lower, marked R, by Russell's. The upper pair, marked s, are space curves, the upper of the two as before being found by Clark's formula, and the lower by Russell's. Thus if it be desired to find P and t corresponding to s=2500, draw a parallel to O B half way between 2 and 3 on the line O A till it cuts the two space curves, then drop perpendiculars from these points of cutting on OB, cutting the time curves. These ordinates will give the time by the two formulæ, and the abscissas on O B will give the corresponding values of P. Thus we find t_R=90 sec., P_R=11160, t_c=91 sec., and P_c = 12370.

It will be seen by looking at eqs. (23) to (28), and remembering that by Clark's formula μ_2 depends on W and therefore on M, that no effect will be produced on the values of s and t by changing W, provided that P is changed in the same ratio, and v is unchanged. The same holds only *approximately* for Russell's formula, since in this μ_2 is independent of W. Thus we can find the relation between P, t and s in stopping a train of any weight moving with a velocity of 60 feet by these same curves, and if a series of such curves were constructed for different values of v we should have a diagram applicable to any case. Similar diagrams might also be made for the case in which the train is getting up speed. Now let us see what time is lost in stopping. Taking the same express train we have generally considered, suppose that it stops in 2500 feet, and in 91 sec., as just found, and that it gets up the velocity $v=60$ in 18084 feet, and in 483 sec. as fouud by Clark's formula; then the entire space passed over in starting and stopping is 20584 ft., and the time occupied is 574 sec. Now the time occupied in passing over the same distance at 60 ft. per second is $\frac{20584}{60}=343$ sec., so that the loss of time $=574-343=231$ sec. $=3$ min., 51 sec., to which must be added the time during which the train is actually at rest, varying usually from 0 up to 20 minutes.

Thus it appears that the loss of time in the actual processes of stopping and starting is comparatively small.

Let us now take up the subject in a somewhat different way. Suppose we have two stations 30 miles $=158400$ ft. apart, and a train is required to go from one to the other in a given time, say 48 minutes, let us see what will be added to the expense if we introduce a way station, still requiring the whole distance to be made in the same time. We will assume that the train gets up speed in 20000 ft., at which point the steam pressure is so reduced as to keep the speed constant, and that 2500 feet, are passed over in stopping.

Suppose that when there is no intermediate station the rate of uniform speed is $v=60$ ft. per sec. Then by eq. (23) the time of getting up speed is 525 sec., and by (26) that of stopping is 91 sec. The distance passed over at a uniform rate is:

$158400-20000-2500=135900$, and the time is $\frac{135900}{60}=2265$ sec.; therefore the whole time is $2265+525+91=2881$ sec. $=48$ min. 1 sec. The value of P while the speed is increasing is 3662.3 lbs., and therefore that of $P_1=P+F=6283.3$ lbs. While the velocity is uniform $P_1=R=5667$.

In the first case the work $=L_1=20000 \times 6283.3=125666000$ ft. lbs.

In the second case the work $=L_2=5667 \times 135900=770145300$ ft. lbs.

$L_1+L_2=L=895811300$ ft. lbs.

Now if a station be made at some intermediate point a greater velocity must be given to the train when it is moving uniformly. We will suppose that the train just comes to rest and then immediately starts on again. We can arrive at the value of v by a series of trials, a first approximation being obtained by supposing the same time to be occupied in stopping and starting with the new value of v as with the old. Thus if we subtract from the whole time, *i.e.* 2881 sec., twice the time of starting and stopping, or $2(525+91)$, the remainder is the time during which the train moves uniformly. The corresponding space is $158400-2(20000+2500)$, and if the latter be divided by the former we have $v'=68.7$ ft. This is evidently too large, because the average velocity of stopping and starting being greater than before, the *times* will be less. By trying successively several numbers smaller that 68.7 we find that $v'=65$ ft. is very nearly the correct value. For corresponding to $v'=65$, we have time of starting $=485$ sec., time of stopping $=80$ sec., time of moving at uniform rate

$$=\frac{158400-2(20000+2500)}{65}=1745 \text{ sec.}$$

$\therefore$ the whole time $=1745+2(485+80)=2875$ sec., which differs only 6 sec from the required time, and shows that 65 is a very little too large. It is near enough, however, to the true value for our purposes. We find also corresponding to $v'=65$, $P'=4298.1$, and therefore $P_1'=6919.1$, and $F+\mu_2 v'^2 R'==2621+3574.56=6195.56$. Hence

$L_1'=6919.1 \times 2 \times 20000=276764000$ ft.lb.

$L_2'=6195.56 \times 113400=702576504$ ft. lbs.

$\therefore L_1'+L_2'=L'=979340504$ ft. lbs., and $L'-L=83529204$ ft. lbs. is the work expended over and above what was expended when there was no intermediate station. To see what $L'-L$ means, we will find how far it would carry the train at a uniform speed of 60 ft. The distance is $\frac{L'-L}{R}=\frac{83529204}{5667}=14739$ ft. a little over $2\frac{3}{4}$ miles. Thus the extra work required on account of the inserted station, would be sufficient to carry the train over $2\frac{3}{4}$ miles at its ordinary rate, and the question to be decided would be whether the gain of time, amounting to 247 sec. or 4 min. 7 sec. would be of sufficient value to offset the loss of work. The disadvantage of the way station would be shown in a yet stronger light if a stop of several minutes were made there, and the whole distance were still traveled in the same time.

Most of the results of this article have referred to a passenger train whose total mass was taken as 18993.8, g being assumed at 32.2. If the value of g be different from 32.2 the only effect will be to cause the results to refer to a train whose *weight* is a little greater or less as the case may be.

THE GROWTH AND PRESENT POSITION OF THE SCIENCE OF MACHINES.

By Professor A. B. W. KENNEDY, C.E.

From "Journal of the Society of Arts."

I have to-night to endeavor to give you a sketch of the development of a science, or branch of science, in which the members of the Society of Arts may be supposed to have some special interest—the science of machinery. Like other sciences, this one began to grow long before it existed. Anything like a complete scientific treatment of machines—their form and objects and dimensions—is of very recent date, and even the first faint traces of such a treatment do not date back more than a century and a half. Without going back to Hero or Archimedes, however—to say nothing of Aristotle –I must start at a somewhat earlier period than that I have named, if I am to give you, as I hope to be able to do, any connected account of the ways in which machines have been viewed and treated by the men most capable of thinking about them, from the time when they began to put their ideas into writing—from the time, that is, at at which their ideas first become known to us. We shall find that it is hardly possible to say exactly when these ideas first took anything like a scientific form, and it is not a question in which one can feel any great interest. It is more important and more instructive to notice that we can trace continuous, uninterrupted development, step by step, from Ramelli and Leising right on to Tredgold, Willis and Rankine, Monge and Hâchette, Redtenbacher, and Leuner, and Reuleaux. It is the course of this development which I wish now to indicate to you.

At the outset, let me just remind you that it is not the growth of the machines themselves about which I have to speak, but the growth of their theory. Many names that are familiar in connection with the former have little place in regard to the latter, as you will find, and *vice versa*. Nor have I this evening to do directly with the growth of the science of mechanics, which I find had, by a little oversight, been announced as my subject. The general course of the connection between mechanics and machine science has been something like this: At the very beginning mechanics was certainly identical with the science of machines, but although this was the case—although, that is, the science of mechanics contained all that was scientifically known about machines—yet we shall find that the two were in reality very far separated. The engineer made his machines with scarcely any knowledge of mechanics, the mathematician evolved his mechanics with very little reference to machines. In time, the nominal connection between them grew weaker, as the science of mechanics received higher and more general treatment, while, again, later still, we find certain portions of that science specially connected with engineering treated by themselves as "practical mechanics," the more general treatment of the subject for its own sake being called "theoretical mechanics." By this time, however, machine science, or some part of it, had begun to have separate existence, and stood beside, rather than coincided with mechanics.

With this much of introduction, I may enter at once into my subject.

The literature of machinery dates from the latter part of the sixteenth century, and then it certainly makes an excellent start. Within a few years of each other appeared the "Mechanicorum Liber," of Guido Ubaldus (1577); the "Theatrum Instrumentorum," of Besson (1582); and the "Arteficiose Machine," of Ramelli (1588), each of them a substantial folio, such as a modern publisher would scarcely venture to bring out, and a modern public would hardly purchase very largely.

Let me indicate to you, as briefly as I can, the view of their subject taken by the writers I have named, and others of the same epoch. Its most noticeable characteristics is perhaps the absolute separation between mechanics and machinery which I have already mentioned. In the time of Archimedes, the mathematician was the engineer; the student of mechanics was the inventor of machines. During the centuries that had passed over the world since then, their relative position had altogether changed. The bulky "Mechanicorum Liber"—which consists of treatises on the balance, the lever, the pulley, the wheel and axle, the wedge and the screw—contains little that had not been given by Greek mathematicians centuries before. The problems are much the same, the point of view from which they are looked at is much the same, the solutions are much the same. Nominally, they have to do with physical data and phenomena; actually, they are no more than geometric exercises worked out in the study. But while the science of mechanics was thus in its infancy, gradually becoming a not unimportant branch of mathematics, the class of men to whom in time it was to be of the most direct value—the forerunners of our present engineers—had found themselves face to face with a very different set of problems. They had had to make pumps and water-wheels, mills, apparatus for land and water transport, hoisting apparatus, bridges and roads and viaducts, and so on. Every one of these brought them into direct contact with nature. Their difficulties were not connected with lines and circles, and mathematics could help, as yet, very little in solving them. They had to deal with some of the most complex problems in physics—problems which, even now, we have not completely mastered; and physicial science was as yet unborn. It must be admitted that the cut-and-dried lever and wedge and wheel of the mathematician, and his neat geometric figures cannot have appeared to the engineer, struggling mightily to utilize and control forces which he could not see and energies which he could not understand, to have much direct bearing on his work. We cannot wonder that, when at length he became articulate, his utterances took a form very different from those of the writers on mechanics.

The "Mechanicorum Liber," as I have said, is a collection of treatises on the mechanical powers; that unfortunate jumble of apparatus which has played the part of the "old man of the sea" to machine science, and which we have scarcely yet got altogether thrown from our shoulders. It is purely theoretic, and its theory is, in general, sound enough and useful, of course, now that we know how to apply it. At the time, it was no doubt regarded as a mathematical book, the "simple machines" only illustrating mathematical problems, and not as setting forth in any way the principles upon which machine design was based.

The "Diverse et Arteficiose Machine" of Ramelli, and the "Theatrum Instrumentorum" of Besson, are much more interesting to us. The authors were both men of distinction in their time, Captain Augustus Ramelli being an engineer in the service of the "most Christian" King of France, to whom he dedicates his book, and Besson, a doctor of mathematics.

Their books, therefore, which are very similar in form, will enable us to form some idea of the way in which the best engineers of that time looked at their work. Ramelli's, I may mention, is given, chapter by chapter, in both French and Italian; Besson's is in Latin, but a French translation of it was published in 1596. They consist solely and simply of descriptions of machines. There is absolutely no referenee to general principles, not even to the mechanical powers. One plate (the engravings in the "Arteficiose Machine" are extremely beautiful) follows another, and for each there is a separate description. A connection is recognized between machines having the same general purpose, but this purposive connection seems to be the only relation distinctly realized by the authors. Ramelli, *e.g.*, begins his book with a hundred and thirteen machines for raising water. Each one has a plate and a description to itself, and each description begins in the same way: "C'este cy est un autre façon de machine par laquelle." . . . . "Une autre façon de machine par laquelle." . . . . "L'effet de ceste autre façon de machine est de faire . . . monter l'eau," and so forth, and goes on to detail the whole construction *de novo* from the suction-pipe to the discharge-nozzle. In this way, nearly every machine is described many times over; each one comes first worked by a water-wheel, and then by a man or an animal. Then the same machine reappears, with such minute alterations as the substitution of a figure of Neptune for the pipe through which the water is discharged, &c. But each time the whole description is repeated. Further on, come other machines, possible and impossible, treated in just the same way. A screw lifting-jack, for instance, is a machine for lifting a prison door off its hinges, and after being described separately once, is several times re-described in this particular application. A wrench is a machine for breaking the bars of a grating, and so on.

The authors of these early *theatri* view each machine, as a whole, only as one piece of apparatus, intended to do one particular piece of work. They recognize that, as a fact, it is made up of a number of different pieces; but, as soon as any one piece has become part of the machine, it seems to lose its identity; it no longer has any separate existence. An exactly similar piece in the next machine has to be again described, and so on in the next, and the next. Everything, moreover, as I have said, is looked at purposively in the most specialized fashion. The general ideas of, and of course the corresponding words for, pump, crane, hoist, wrench, and so on, are wanting. One is a machine to lift water from a well by means of a man; another to lift water from a river by means of a man; another to lift water from a well by means of a water-wheel; one to raise water for a fountain by means of a water-wheel; another by which a man can raise water for irrigation; and so on with the other classes of machines.

Then, further, there is no critical examination of the machine whatever; not even a statement that one is better than another, or simpler or more efficient. There is nothing but a statement of the machine's purpose, and a description of its construction. Ramelli's descriptions are very detailed, his plates being carefully lettered throughout. Besson's descriptions, on the other hand, are not nearly so minute, for the reason, among others, that his system of references is not a very convenient one. To avoid putting letters on his plates, he uses special names for top and bottom, right and left, calling them septentrionale, meridionale, orientale, and occidentale (these words being printed on every plate), and also special names for the corners, and then indicates, by the help of these, the portion of the plate in which any particular detail is to be found.

It must, of course, be remembered that the machines described in the *theatri* had no actual existence in many cases. Which did exist, and which did not, is, of course, now impossible to say, but certainly many of them are physical impossibilities (the lazy-tong bridge and the ship-lifting lever, for example). Ramelli's machines are drawn in such minute detail that I cannot help believing that he actually made models of them, from which his drawings were made. Besson, on the other hand, while far less minute in his details, contains fewer machines which are obviously mere inventions never practically executed.

The drawings in all the works of this time are, of course, in perspective, not arranged in plan and elevation—an improvement which was not long in coming.

I have endeavored to give you some notion of the light in which the machine appeared to the very earliest authors who gave it a place in literature, at a time when as yet machine science did not exist. We have now to trace the growth of this special branch of literature and the development of the science to which it gave rise.

The attempt to connect mechanics with machinery was very soon made. In 1608, the first volume of Leising's "Theatrum" was published, in which the editor, mourning over the lamentable ignorance of practical men, incorporated a translation of a short Latin treatise, lately published, on "The Proper Foundation and Understanding of the Balance and Weight," by "that learned and honorable physician and mathematician, D. Eualterus Herminius Rivius," to which he added some general chapters on the meaning of the word machine, the scope of machine study, the origin of machines, the first inventors, and so on. But, as was to be expected, the introductory treatise, which is to give all readers full instruction for the understanding of all the machines, has, after all, very little to do with what follows. The author soon gets tired of his high horse, and descends to very perfunctory descriptions of his plates, which are to a great extent inferior reproductions of those given in the earlier and larger *theatri.*

The work is notable, chiefly on account of the distinct recognition in it, by an engineer, of the fact that his art had also a science. For, although many former works on mechanics had professedly treated of the science of machinery, it is obvious that, to the actual engineer—the veritable constructor of pumps and water-wheels, and other such "engines"—no such science existed. He worked away at his clumsy, but useful contrivances, without saying—or, at least, without writing—much about them; but the lever and the balance, in their mathematic form, were wonders to him, mysteries—things hard to be understood, but greatly to be respected. He did not recognize at first that they had much connection with his work, although he was continually making use of them. And this is not to be wondered at, for the theorists delighted chiefly in describing the enormous loads which could be raised by them, and the smallness of the effort required for that purpose; their levers would do anything—on paper. But he, poor fellow, found that the nearest approach he could make to the mechanician's lever was a ponderous, unwieldly wooden bar. It certainly gave him a very distinct "mechanical advantage;" but then, the effort required to move his load was something out of all comparison with the breath, or the touch of a straw, or pull of a thread, which ought, with a real lever, to do such wonders. And, worst of all, his lever required a very considerable effort to move itself, and that very few of the paper levers seemed to do. Thus, altogether, we cannot be astonished that he failed to discover at first any definite connection between his own machines, which were so hard to move, and these wonder-working contrivances, that did so much with so little trouble. They belonged to distinct *genera.* Herr Leising is not moved to astonishment over his pumps and bridges, and lifting-jacks; it is only of the "lever" that he tells us, very philosophically, that, "when we consider the matter, we shall find that those things which perform wonderful actions must spring from wonderful causes." "Is it not extraordinary," he says, "that an extremely heavy load can be easily raised by adding another weight to it?" and proceeds to discourse on the wonderful qualities of the circle, "the most beautiful, complete, and strong of all figures," and, following Aristotle, traces to these all the mechanical wonders of machines.

The timid attempt of Leising to combine mechanics and engineering was soon followed by bolder steps in the same direction. The work of Solomon de Caus, "Des forces Mouvantes," was published in 1615. It differs from its predecessors in several points. There is a distinct recognition of the connection of machinery with physicial science generally, and there is really some attempt to place machine problems on a scientific basis. The attempt breaks down altogether, as did most other such attempts for more than a century after the time of Caus; but it is not with its success, but with its existence that we have here to do.

His book commences with a series of physical definitions and theorems, and then, after examining the "mechanical powers," he goes on to "problems," which are, for the most part, such as require for their solution simply the description of a machine, old or new. Between the theorems and the problems there is no direct connection, but a stage had been reached at which it was recognized that engineering problems were based on physical and mathematical science; and that was a great deal. But the sciences had to advance much further before they could be actually applied to the complex problems of engineering, so that at present they could simply be put side by side. It was reserved for after generations to show the real nature of the connection between them.

Caus does, however, make two distinct and important steps forward. First of all, in his plates he shows the essential part of a machine, sometimes apart from their ornamental surroundings. The head of Bacchus, through whose mouth water is pumped, is no longer as necessary to the pump as the piston itself. And secondly, he gives what may be called "working drawings" of their details, in the conventional representation now universally used, and called orthographic projection. He calls such a drawing an "orthographie." Previously all drawings of machines had been given in perspective. All engineers will recognize the importance of this change. In this book, then, which is before you, is perhaps the first published working drawing, or scale drawing, of any machine.

I am sorry to say, that our own country did not do much at this time towards the development of machine science, whatever may have been done here in improving machines themselves. The first work in our own language upon mechanics, and almost the first work on the subject published in England, bears on the title page the inscription, "Mathematicall Magick, or the Wonders that may be performed by Mechanicall Geometry. In 2 Books. Concerning Mechanicall $\left\{\begin{array}{l}\text{powers.}\\ \text{motions.}\end{array}\right.$ Being one of the most easie, pleasant, useful (and yet most neglected) part of Mathematicks, not before treated of in this language. By J.W., M.A." The author was no other than John Wilkins, afterwards Bishop of Chester, at that time chaplain to the Prince Elector Palatine. He has certainly succeeded in producing a very entertaining book, but it cannot be said that he did anything to advance the science of which he was so much enamored. I fear, indeed, that his book had an opposite effect, if it had any effect at all. The Bishop seems to have been chiefly attracted by those parts of his subject which savored of the marvellous, in this as in his other writings. He gives us a drawing, for instance, of a train of wheel-work and pulleys, by means of which a puff of breath, or a pull by a hair, or a push with a straw, could uproot an oak-tree, or, "a power, which is much less than the one-hundredth part of a pound will bee able to move the world;" and he gives us all his calculations to show it. But, as usual, the poor engineer fares but badly at his hands, for he goes on, "It were needlesse to set down any particular explication how such mechanicall strength may be applyed unto all kinds of local motion; since this, in itself, is so facill and obvious that every ordinary artificer doth sufficiently understand it." Wilkins was very credulous as to ever-lasting lamps, and subaqueous traveling, flying chariots, and so on. In speaking of flying, he tells us that "the wings of a bat are most easily imitable; perhaps nature did by them purposely intend some intimation to direct us in such experiments, that creature being not properly a bird, because not amongst the *ovipara*, to imply that other kind of creatures are capable of flying as well as birds, and if any should attempt it that would be the best pattern for imitation." One good service Wilkins certainly did, however. Although most amusingly anxious to discover and believe in a perpetual motion, he examines a number of proposed arrangements for that purpose, and points out that all of them are based on misconceptions, and that all have failed on trial.

After the time of Caus no very considerable progress seems to have been made until near the close of the century. The "Nouvelle Invention de lever l'eau," of Isaac de Caus, engineer and architect to Charles I., published in London (in French), in 1657, does not show much difference from the work of the elder Caus, from whose book most of his engravings are copied. During this period appeared also Moxon's "Mechanick Exercises; or, the Doctrine of Handyworks" (1677, and intended to be continued monthly). It is a detailed description of the construction of lathes, tools, locks, &c., and of technical processes and methods, and was thus entirely untheoretical. No doubt the book was a valuable one in its own range and period, although it does not concern us here.

Towards the end of the seventeenth century we can see distinct marks of progress, made, no doubt, slowly, but becoming visible to us more or less suddenly. Of these, the two most important are the use of geometrical construction in the solution of mechanical problems, and the consideration of the strength, or molecular resistance, of the materials from which the machines are formed. Of the first of these I shall have to speak further on. I shall only say here that the earliest work on mechanics in which I find constructions systematically used, in place of elementary algebraic proofs or arithmetic illustrations, is the "Traité de Mécanique" of the mathematician De La Hire (1695), which, on this account, marks certainly a notable epoch. It is worth noticing that De La Hire, in resolving forces, uses a triangle, and not a parallelogram. The overpowering influence of Newton, coming but a few years later, has made the use of the parallelogram almost universal, and it is only within the last few years that we have returned to the simpler figure. Even now, in books from whose authority one would not expect it, we find that conservative instincts have overmastered reason, and the student is told to draw five lines in order to see half the solution of a problem which can be perfectly solved by three.

De la Hire's work is also remarkable as being one of the earliest in which the resistance of materials to fracture was treated of. This subject, the "strength of material," which now forms the physical basis on which a large branch of machine science—namely, machine design—rests, was first worked in by Galileo, who published a theory of beams. Mariotte had, at this time, also written on the same subject. De La Hire introduces it as an essential part of mechanics, which meant, with him, the science of machines. In his chapter on the subject he adopts the theory of Galileo, which was an erroneous one, but which, nevertheless, in certain special cases, gave results identical in form with those now known to be true. In the absence of experiments to determine the value of constants, of course the theory, right or wrong, did not admit of any direct application in machine design. Another century had passed before we find traces of rational proportioning, by engineers, of the dimensions of the rods, or links, or beams of their machines to the loads or pressures they had to sustain.

Some practical work in machine design, however, De La Hire did, for he gave constructions for determining the forces of cams, and of the teeth of spur wheels, which might have been, and no doubt were, used in practice. If this were the case, we have here the first definite point of contact between the theoretical mechanics of the time, and the actual work of machine design or construction.

In passing, I may mention, that just at this time, viz., in 1696, the second English work on mechanics was published. Its title gives a good idea of its general drift, "Mechanick Powers: or the Mistery of Nature and Art Unvailed; showing what great things may be performed by Mechanick Engines in removing and raising vast weights with little strength or force; . . . . . a work pleasant and profitable for all sorts of men, from the highest to the lowest degree, and never treated of in English but once before, and that but briefly." Its authors were Venterus Mandey and James Moxon. While the work of these worthies was doubtless a useful one to many readers, it does not in itself do anything to advance machine science.

The chief article of faith of writers on machine-mechanics up to this time, and indeeed for long afterwards, was, that certain contrivances called "mechanical powers," or "simple machines," were the elements from which all other machines, "compound engines," as they were called, were built up. There can be few things more remarkable in the history of science than the way in which this statement has been repeated and repeated, for centuries, without the least hint that it was not all right, by men who would have seen, if they had but honestly thought out the matter for themselves for five minutes, that it was not true. It is a somewhat striking commentary on the value of the historic argument for the truth of an opinion or hypothesis. The statement was first made by those who, with very limited knowledge and experience, really believed it to be true; it was repeated over and over again by others of greater knowledge and experience, simply because they would not take the trouble to think for themselves, to throw off the overpowering pressure of an ancient and venerable tradition.

The matter becomes in this case the more remarkable because no two writers agree as to which combinations are to be called the "mechanical powers," nor how they are related to each other, nor indeed of what each one essentially consists. Still less does anyone succeed in showing, either by analysis or synthesis, how the compound machines are built up from the simple ones. This very vagueness, no doubt, added greatly to the ease with which they might be dogmatized about. But no sham can exist without doing evil, and here the evil has been lasting and serious. Attempts to apply mechanics to machinery began naturally enough by applications of mechanics to the mechanical powers, the simple machines. But their beginning was their end. The connection between the simple and compound machines was so obvious that it went without proof, while at the same time it was so subtle that all attempts to get hold of it were failures. And so for two centuries we have over and over again the same story. The writer of a treatise on machine-mechanics gives us drawings of impossible levers, improbable screws, and unheard of wedges, and duly repeats, with more or less of variation, the received theory of these instruments, and here he stops. I fear the average engineer did not derive much benefit from his well-intentioned instructor. His lever was not a bent rod resting upon a triangle like the lever in the books, his screw never would do the wonders that it ought to have done, and his "compound engines" did not, in general, contain wedges or "funicular machines." We recognize that there may have been some good ground at one time for the now traditional distrust of "practical" men for what they call "theory." Certainly at one time the theory may have been called unpractical in the fullest sense of the term.

From the beginning of the eighteenth century the interest in the "marvellous" characteristics and properties of machines diminishes, and they are treated much more as familiar things. A healthy spirit of scepticism, moreover, respecting the prodigies to be performed by the mechanical powers, began to spring up. Thus Sturm, in his "Mathesis Juvenilis" (of which a translation was published in London in 1708, and which was a very great advance on Mandey and Moxon), devotes a good deal of space to the demolishment of Archimedes and the world-moving lever with which tradition credits him. After elaborately estimating the probable weight of the earth, he calculates through how many thousand million miles Archimedes would have had to move his hand in order to move the earth the thousandth of an inch, assuming most exactly that the earth rested on his lever at one foot from the fulcrum, and that he could exact a pull of a hundred pounds, and calculates also how many hundred million years the operation would have occupied. From this very matter of fact point of view, he comes to the general conclusion that a great deal of the "tall talk" which had been indulged in as to the power of the lever and so on, was nothing more than talk, and was, therefore, much to be deprecated. He was one of the earliest to realise clearly a point that had been known well enough before, viz., that (to use his own words) "the immense force of the mechanical powers . . . . . would be infinite and altogether stupendous if it were not that the greater their force is the more slow their operations are." His services in this respect deserve special mention, for the matter was one which had led to the writing of much nonsense. The worthy Bishop Wilkins, for instance, although he knew the fact perfectly well, and even wrote a chapter about it, yet seemed to realise it so imperfectly, or else was so enamored with anything savoring of the marvelous, that his knowledge of it does not for a moment prevent him from giving a detailed description of his tree-raising machine and others of the same sort, or from such statements as these:—"By these mechanical contrivances, it were easier to have made one of Sampson's hairs that was shaved off, to have been of more strength than all of them when they were on."

Having mentioned Sturm (who was a professor at Altorf), I may further use his work as an illustration of the utter helplessness of the system of mechanics, based upon the "simple machines," in the presence of the more complex instruments of every-day life. In the "Mathesis Juvenilis" is a chapter headed, "Compound engines and their forces, which may immensely be increased." Here was certainly the place to say something about the important machines used in the arts, with at least the existence of which he must have been perfectly familiar. But it is obvious that he did not really believe these machines to be formed from his elements, for he can only mention two "compound engines," of which one was the lifting tack, and the other a machine like that "probably" used by Archimedes (the "Charistion") for drawing his enemies' ships out of the water. Engineers looking to the book for help in their work, had to content themselves with this, and the cheering intimation, than besides these two "compound engines," "there are innumerable ones daily invented, as also several that have been actually made and tried by experience!"

The well-known "Theatrum Machinarum," of Leupold (1724), marks an epoch in the literature of machinery. It is an immense work, extending to nine folio volumes, and containing descriptions of all the principal classes of machines used in the arts. In it we can mark most distinctly the transition from the old to the new standpoint, from wonderment to criticism. (Two earlier works cited with favor by Leupold, Mögling, and Jungnickel, no doubt led up to him, but these I have not been able to find in London.) Leupold was a competent mathematician as well as a practical engineer, and his critical remarks are often sound and acute enough, taking into account the state of contemporary science and practice. The most notable feature about the work is one which the author does not remark or appear conscious of. To Leupold the machine is no longer a whole—as to Ramelli and Leising and most of the earlier writers—but a combination of parts, each of which may be isolated and examined separately. Leupold does not state this anywhere, in as many words, he simply takes it for granted—no doubt in this merely carrying on one step further a process which had been developing itself for a century past. After his definition of a machine, which runs:—"A machine or engine is an artifice by which some advantageous motion can be obtained, and something moved with a saving of time or force which would not otherwise be possible," comes the stereotyped "Machines are either simple or compound. The simple machines are the so-called mechanical powers," viz., . . . and so on. . . . . . "Compound machines consist of two or more similar or different simple ones." But like every other writer, he no sooner makes the statement than he throws it aside and uses it no more. He goes on to treat in separate chapters, and in similar ways, not only the mechanical powers but also cranks, fly-wheels, pendulums, cams (oval discs, he calls them), lazy-tongs, weights and springs. In these chapters, and throughout his book, it is evident that he looks at the machine essentially as a combination of mechanisms, the first great step in machine analysis. Leupold also treats systematically the external moving forces or agents, and the means employed for most conveniently utilising them; cranks and wheels for human and animal power, the sails of wind-mills and the wheels of water-mills. He has a chapter also on the "force of fire," but of this, perhaps, the less said the better, for at the time he published his theatrum, his idea of utilising the said force in a fire-wheel was not a very satisfactory one. He had not at the time invented his high-pressure engine.

It is evident from the plates in Leupold's volumes and those of his contemporaries, that a very great improvement had been gradually taking place in the accuracy of construction of machines, *i. e.*, the accuracy with which their different parts were made to move in the required paths. An engineer of Ramelli's time can scarcely have recognised that each of his rods and links should have some definite motion, for certainly (judging from his drawings) they must have had very indefinite motions indeed. The constraint of the motion had been obtained and its necessity tacitly recognised at the same time. The improvement in the construction of machines pointed out the direction for the development of their theory, and so far as Leupold's work was scientific, it was just this part of the science that he took up. His chapters on mechanics are very elementary, and contain scarcely anything that had not been given many times before, and his detailed work is mostly descriptive rather than scientific. He does, however, distinctly apply geometrical methods to the determination of the forms of different parts of machines, and to the investigation of their motions; and here we have the beginning of machine-kinematics, the first appearance of any science of machines separate from mechanics.

From this time the writers and books on machinery rapidly increase in number, and we can trace the development—or, if you like, the formation—of machine science along three distinct lines. Of these, one has the direction I have just indicated, and may be summed up, in one word, as the geometry of machinery. It connected itself with the motions—considered merely as changes of position—of the various bodies forming the machine. It included both the study of these motions in themselves and in their relations to one another, and the study of the geometric form of the bodies by which particular motions could be obtained. I think there can be no doubt that the increasingly great necessity for such investigations, and the necessity for carrying them on by grapho-geometric methods, in order to be of use to practical men for technical purposes, must have had an important influence in the bringing back of the study of pure geometry, which had for so long been neglected by mathematicians. In any case, the reaction in favor of geometry at the end of the last century soon had its effect on machine science. At the foundation of the Ecole Normale in Paris, in 1794, Monge introduced there his descriptive geometry, and his colleagues and successors—Hâchette, Lanz, Betancourt, Borgnis, and others—systematised machine-kinematics, and brought it into the form in which, essentially, it has until recently remained.

The application of geometry to machines formed one line of advance. A second was formed by the applications of physics, especially in connection with hydraulics, and, later on, with heat—it would hardly be correct to speak of thermo-dynamics at that date. These subjects were, of course, connected chiefly with the theory of prime movers, and the former was, comparatively speaking, of far greater importance then than now, for, at that time, water-wheels were the most important prime movers, and the raising of water was, perhaps, the most important application of machines. Among the names most closely connected with the progress of machine science in this direction, are those of Belidor, Prony, and Langsdorf. Belidor's "Arch. Hydraulique" (1782) was or its time an extremely valuable work; it is a treatise, theoretical and descripve, on every possible machine or structure which has anything to do with water. In Prony's "Nouvelle Architecture Hydraulique" there is far less description and more theory; and in Langsdorf's "Lehrbuch der Hydraulik" but little of the descriptive matter remains. His pages bristle with immense formulæ, and long explanations of the symbols used in them. Considering the great uncertainty of many of his data, and the want even now of trustworthy experiments on the subject of which he treats, I cannot imagine that his closely-printed volume was of much direct use to any engineers in their practical work. None the less, his labor was well spent in showing that the subject was one which could be treated scientifically, and in which results could be obtained by other than the mere "rough guess and divide by two" method, which had been till then almost universal.

I have mentioned De la Hire's work in connection with the resistance of beams; it was merely theoretical, without numerical values of any constants, and interesting, therefore merely historical. Since his time several great mathematicians had written on the subject, and notably Bernouli had pointed out that Galileo's theory of beams was incorrect, and that there existed in a beam a neutral axis, on the two sides of which the senses of the stresses was opposite. He had not continued to work at the subject, however, and so little practical interest was taken in it, that for many years no engineer seems to have even alluded to it, or thought it worth while to work at it. It is only towards the beginning of the present century that we find definite progress made in this direction in applying the laws of the strength of materials to the design of machinery.

Even in such works as those of Prony and Langsdorf, already cited, no mention is made of the possibility of proportioning the sizes of the pieces of a machine to the loads they have to bear, or the pressures they have to resist; the only exception I have found is a chapter by Langsdorf on the thickness of water-pipes. This can hardly have been owing to any inherent difficulty in the subject, for the author did not scruple to attack the much more complex problems of hydraulics unflinchingly. No doubt it was due chiefly to the lack of experimental data, for without any means of determining the values of constants, it must have seemed a somewhat useless task to write down formulæ. The earlier experiments of Müschenbröck and others had been conducted with woods of different kinds, and had given results so discrepant as to be of little practical value. Iron was now more and more superseding wood as a constructive material; but as yet estimations of its strength were little more than guesswork, and, indeed, for some time after determinations of the tenacity of iron had been made, you find it given in books only as so many times stronger than pine or oak as the case may be.

I have not mentioned our own country in speaking of the progress made during the last century, and for the good reason that our engineers had been busying themselves about other matters, and had aided the progress only indirectly. If my subject were machines themselves, and not their theory, I should, as you know, have much to say about the illustrious engineers of the eighteenth century and the splendid work which they did. But I must not turn aside to this tempting theme—and it must be said that these men worked for the most part empirically, and that, although machine science is enormously indebted to them, their influence on it was almost altogether indirect. It thus happens that the English engineering literature of the period in question scarcely calls for remark, in fact, it had scarcely any existence. The Registrar of the Society of Arts published, in 1772, a large volume of descriptions of machines and models, possessed and approved by this Society, and a second similar volume was issued in 1779; but these were purely descriptive, like the more extensive "Description des Arts et Metiers faites ou approuvées per Messieurs de l'Academie Royale des Sciences," which was published in Paris in 1761, in eleven folio volumes. Books treating engineering subjects scientifically, hardly ever appeared; probably the engineers themselves had neither the time nor the knowledge to write them, and certainly no one else had. The earliest record I can find of anything like systematic experiments on the strength of iron in this country, and one of the earliest anywhere, and the application of their results to machine design, is contained in a little book, published in 1803 by a Mr. John Banks, who styles himself "Lecturer on Philosophy." The author not only gives particulars of a number of experiments on a tolerably large scale, which he seems to have conducted personally, on beams of different forms, but indicates by numerous examples the application of his results to the designing of machine details. Banks adopts Galileo's erroneous theory as to the resistance of beams without question, but in most of the special cases of which he treats, the results are not much affected by it. He did not add anything to our knowledge of the theory, but his work, in rendering possible the application of theory, cannot be overlooked.

But Banks was certainly not the only one who was experimenting on the strength of iron at this time, any more than England was the only country in which such experiments were required. We find that the science of design—of proportioning form to stress—extended very rapidly everywhere, and was recognised as a promising field for further investigation. Olinthus Gregory, in his "Mechanics" (1806), devotes a good deal of space to it, though his adoption of Galileo's theory brings him into some queer mistakes; and Buchanan's "Essays on Practical Mechanics" (1808, and subsequent years), form early contributions to this part of the science. Both writers refer to Banks. Among the first, if not the very first, to state the theory of beams correctly, and at the same time in a manner accessible to others than mathematicians, was Prof. Eytelivein, of Berlin, in his "Statik festec Körper" (1808), who also pointed out that time was a most important element in all matters concerning the resistance of materials to load. In this country we owe a great deal to Tredgold in this connection. He was probably the first to give anything like systematic treatment of machine details in reference to their strength. This he did in his steam-engine, 1826. I have now traced the development of machine science up to a time within the memory of living men. It remains that I should point out its more recent course, and indicate so far as I can its present condition. From a purely scientific point of view this is the most interesting part of the subject, but to treat it in a way corresponding to its scientific interest would require far more time even than I have already given to the more distinctly historical part. But although scientifically of so great interest, it could hardly be made interesting to an audience like the present, for anything like a full treatment of it would involve so many mathematical and technical details as to make it almost unintelligible to all but the initiated. I must, therefore, content myself here with a very brief review of the matter.

Looking first, then, at the mathematical side of the science, the first professors at the Ecole Polytechnique, to whom I have already alluded, made such enormous advance all at once that it was years before their contemporaries caught them up. Prof. Willis, in his "Principles of Mechanism" (1841), did yeoman's service, as every one knows, for his favorite subject, and his name is the most distinguished of those who have written upon it since the commencement of the century. He did not essentially alter its basis, and his system does not seem a satisfactory one, but his investigations in many directions were none the less extremely original and valuable. He has had innumerable followers both here and on the Continent, and among them Rankine is to be reckoned, whose original genius did good work here, as in other branches of machine science. Within the last few years, however, the orthodox faith in the old classification of mechanics has received a rude shock from the impetuous attack of Reuleaux, who maintains that they are, at the best, merely empirical, and who wishes not to modify, but entirely to subvert the former treatment of the subject. Reuleaux's leading idea is this:—The analysis of the machine may be carried further than the mechanism, which has hitherto been treated as an indivisible unit. The mechanism consists of certain elements arrayed in pairs—each pair constraining a particular motion (a pin and an eye, a screw and a nut, &c.)—these pairs are linked together by resistant bodies so as to form "kinematic chains," in which the relative motions of each link to every other are absolutely constrained, and the fixture of any one link of the chain constitutes it a mechanism. This method of analysis gives quite a new insight into the relations between one mechanism and another, and renders the treatment of the whole by one general method as easy as before it was difficult. Reuleaux has advanced the science of mechanism in other ways also, but this is his most important work, and one which, I believe, forms the most important step which has been made forward since the beginning of the century. It not only forms the basis of instruction in the principal German Polytechnic Schools, but forms also a foundation upon which already many men are doing valuable work.

The advancement of geometry told upon machine science. The growth of machine science has not been without its effect, direct and indirect, on geometry. Aranhold's "Kinematische Geometrie"—a little pamphlet, containing an amount of original matter altogether disproportionate to the fewness of its pages —we owe, no doubt, to the suggestions, of mechanisms; and still more recently the subject has been carried into higher branches in a most elegant manner by Burmester. These general investigations will react again upon our special cases, and will no doubt be found, as has so often been the case with investigations which at first seem purely theoretical, to have important applications even in the limited region of machine science.

I cannot leave this subject of the relations between geometry and machine science without some mention of graphical statistics. I intended to have spoken about it at some length, but time absolutely forbids me this. I must say only that while graphic methods of calculation had for many years been used to a limited extent, it is only very recently that they have been systematised; and so far as concerns calculations in which lines represent forces, this has been done chiefly by Culman Zurich, who has called his subject "Graphische Statik." He has treated it throughout in connection with the methods of modern geometry. The two studies are, I hope, inseparably connected, and the graphical statics, which should form an essential part of an engineer's education, may be thus the means of introducing into this country some of those modern geometrical methods which ought to form, so far as I am able to form an opinion, a part of the education not of engineers only, but of every one.

In its physical aspects, machine science has, during this century, advanced alongside of physics. The most distinct progress which has been made here has been in the application of thermodynamics, and chiefly in the theory of the steam-engine. There probably was never a case in which the growth of a science and the growth of its children kept pace better. Rankine in this country, Clausius and Leuner in Germany, Hirn in France, as well as many others, whose interest in the subject was more purely physical, have worked so well that we have already a tolerably complete theory of heat engines, and are able to say in every case exactly what an engine ought to do, which by universal analogy must be the principal step towards making the engine do it.

The once popular study of hydraulics has become of secondary importance in connection with machinery, the steam-engine having to so enormous an extent superseded other prime movers. Redtenbacher's treatises on water-wheels and turbines, although published thirty years ago, remain the standard works on the subjects of which they treat. The more recent scientific research in this and allied subjects find its application chiefly in hydraulic engineering, with which we have not here to do.

And now, lastly, as to the progress of machine design, so far as it has been reduced to a science, and connected with the molecular resistance of materials. It was Redtenbacher who first fairly separated this study from mechanics, and systematised and extended it. Indeed it may be said that it was he who created machine design as a separate branch of science. His "Resultati für den Maschineu-bau" was published in 1848, and although much progress in details has been made since then, and his method of treatment may in many cases be greatly simplified, and must in some cases be entirely altered, this work and his published lectures ("Die Maschinen-bau"), remain classics. The direction of progress since his time has been in the more and more complete reduction, to a scientific basis, of the numerous determinations formerly made upon grounds of "experience" alone, that is empirically; and no year passes without some such gains to science at the expense of empiricism.

During the last thirty years a host of experimenters has been at work investigating the strength of iron and steel. As time has gone on the experiments have been made more and more complete and accurate, and in some particular branches of the subject the experiments may be said to be complete, so far as concerns the constructive materials now most used. We have, for instance, thanks in great measure to Mr. Kirkcaldy, little left to learn as to the ultimate tenacity of many qualities of iron and steel, and as to their behaviour when near the breaking point. But, unfortunately, many new fields for experiment are opening up. Engineers are not in the habit —intentionally, at least—of straining the members of their structures or machines to near the breaking point; and, as the behaviour of many materials, when exposed only to small stresses, differs greatly from their behaviour under larger ones, it is now recognized that our knowledge of the strength of a material is incomplete unless we know to what extent it is affected by such small loads as it usually receives in practice. New experiments, so far as they are to have scientific value, must now take this direction, and new apparatus is required for them, much more delicate in its operation than the former machines.

Modern experiments on the strength of materials have given us two conclusions, which have a specially important influence on machine design, and which I must not pass over without mention. The first of these is that the fracture of a material does not depend solely on the magnitude of the load resting on it, but also on the number of times which that load is applied. A bar of iron will be ultimately broken by many repetitions of a load of only about sixty per cent. of the load which will cause immediate fracture; and, as in most machines as well as structures the loads which do occur are repeated over and over again, it follows that the ultimate resistance of the parts of the machine to fracture is not much more than half what is indicated by the ordinary testing machine. The fact was established experimentally long ago by Fairbairn and others, and more lately very completely by the experiments of Wöhler on the "Fatigue of Metals," which extended over some twelve years, and were conducted with specially constructed machines. In many cases, one single piece of material was subjected to many million (in one case once 130 million) repetitions of load. The second conclusion, also established by Wöhler, is of even greater importance. It is, that the resistance of material is not, *cæteris paribus*, dependent on the maximum load to which it is exposed, but to the difference between the maximum and minimum loads, that is, to the range of stress. This discovery has now been fully substantiated in principle, and there can be no doubt that the design of machinery as well as structures, so far as it depends on the strength of the material used, should be based on this law, and carried out by help of formulæ derived from it. Such formulæ have already been investigated, and some of them, (notably that of Launhardt and Weyrauch's addition to it) appear to represent very well the physical conditions of the case, so far as they have yet been determined. The Bavarian Government have already gone so far as to adopt what they should call "Board of Trade Regulations," upon formulæ of this kind. The experiments already made have not been, however, numerous enough to determine the constants required for these formulæ, and very much still remains to be done in this direction.

I am no prophet, and will only say one word as to the future of machine science. Judging from the direction taken by it hitherto, we may infer that as more and more work is done in it we shall be able to get more and more distinctly at the ideal of every machine we design, and to see more and more clearly the highest form of the object at which we are aiming. At the same time we shall understand more and more completely the physical and other conditions which prevent the actual attainment of our object in this form. The more accurately we know these conditions the more closely shall we be able to bring our machines to the best form attainable under them. More than this: as we get to know these conditions more and more accurately, we shall see to what extent they are essential, and how far we can remove them. In the one case we can admit them as modifying our ideal machine, in the other case we get over them with our practical machine. In both processes our practical work and our ideal are brought closer together. Already with some special machines, the real and the ideal have almost met. I look forward to the time—although we shall not see it—when the same condition shall have been reached in the complex machines of every-day life, and when the growth of machine science shall have made it possible to produce a steam-engine as perfect in its whole working as, say, the motions of Sir William Thomson's tide-calculating machine. "After this, the deluge."

FELSPARS, AND THEIR DERIVATIVES.*

By Professor SMYTH, F.R.S.

From the "London Mining Journal."

The felspars, though differing much among themselves, form a group of substances of which the world at large takes but little notice; and yet they are among the most important substances with which nature has endowed the earth. The term "spar" has been in use for a very long time, and was originally given to substances which in their purer condition have a glassy appearance, with a lustre somewhat inferior to true glass, with a certain amount of translucency, lightness, and color, and with a moderate hardness. Amongst these sparry substances the felspars were placed, the prefix denoting the particular kind of spar, being according to some derived from "feld" (feldspar), inasmuch as the substances are usually found in mountains or hills; or,

* A lecture before the Royal School of Mines.

according to others, from "fel" (felspar), as being prominent constituents of rocks. Some varieties of felspar occur so frequently, and so well marked, that an observant person cannot fail to have noticed them. For example, in our London streets, in the crossing places, or in the kerbstones, where the rain has washed away the mud, and heightened the color of the minerals, large crystals will be seen, having a certain definite shape, and of white, brown, reddish, or yellowish colors. These may also be very distinctly seen in the magnificent stones which have been imported so largely into London of late years for the construction of several bridges (London Bridge, Waterloo Bridge, &c.) and of the Embankment. These conspicuous crystals have a peculiar lustre, and often exhibit this peculiarity in structure—that they appear as if a line were drawn down the middle of the length of the crystal, and the one half looks bright and the other dark, whereas from another standpoint the bright and dull sides will be reversed. The latter feature shows the crystal is what mineralogists often call a twin crystal. In the districts of Malvern, or Cornwall and Devon, in the highlands of Dartmoor, &c., we should find large blocks of rock to be composed to a very large extent of this class of substances.

Perhaps the most important of these is what is called "orthoclase," or common felspar. It derives its name from the fact that the crystals have two principal directions of cleavage, which form a right angle with each other. Its hardness is inferior to that of quartz, nevertheless it is greater than that of ordinary spars, since it will make scratches on glass; hard steel will touch it, but with difficulty; its specific gravity is moderate. The crystals in the granite used for the construction of the bridges, &c., referred to above, are mostly of orthoclase, and in these cases it will be seen that the crystals are embedded in a paste. To a rock of this kind the term porphyry is given; if, however, the crystals of felspar are not so very distinct from the rest, but two or three different substances are so distinctly crystallized out, the term porphyritic granite is often applied. Beautiful varieties of this porphyry may be seen in different places; thus the public buildings of Penzance, in Cornwall, are built of a beautiful material of this kind, and reference may also be made to the granite from Shap Fell, in Cumberland, which in the last five or six years has found its way into London for ornamental purposes—columns, &c.; some of the elements of its beauty and utility being its hardness, its pink color, and this porphyritic structure. In the Alps, again, and in the neighborhood of Lago Maggiore, large blocks of granite are thrown from the mountain side on to the plain below by small charges of powder, and often on examining these it will be found that in cracks and cavities the felspar, along with quartz and mica, is beautifully crystallized, sometimes on a large scale. Other notable localities are the Island of Elba, and the Mourne Mountains, in Ireland. In some instances the crystals of felspar are more translucent, looking more like glass; and being found in the Alps, in the vicinity of St. Gothard, they have been named "Adularia felspar," from a mountain there known as Adula. In the Island of Ceylon this variety of clear felspar has a tendency to appear rounded, and is found when cut to present a peculiar lustre, something like mother of pearl, hence it is usually termed "moonstone," and is much valued for ornamental purposes. Felspar is found in other cases with a yellowish, brownish, or reddish tint, and a green variety, from Siberia, has received the special name of "Amazon stone." Some beautiful examples of this latter variety have recently been found near the line of the Pacific Railway, and the Museum owes some fine specimens to the liberality of a lady. If we look at the composition of this orthoclase we find that it is a silicate of alumina, with a silicate of potash, one specimen giving on analysis about sixty-five per cent. of silica, eighteen per cent. of alumina, and fourteen per cent. of potash, with very small quantities of lime and soda. The presence of potash in this substance is of great interest to the agriculturist, since the soils produced by the decomposition of rocks containing orthoclase will be suited to certain plants, to the life of which potash is so important. There are cases where this kind of felspar constitutes an entire rock, as at St. Stephens, Cornwall. Certain building stones contain another variety of orthoclase, known as "glassy felspar," and notable amongst these is the trachyte of the Rhine district, while the magnificent cathedral at Bologne may be pointed out to an example of its use.

To another specimen of felspar the name "albite" is given, in consequence of its whiteness. Crystals of this felspar occur generally on a smaller scale than orthoclase, and are almost universally twin crystals, often appearing as if the crystal had been cut in two and one half turned on the other, so as to form a re-entering angle. It is a silicate of alumina and soda, and thus differs from orthoclase in having the potash of the latter replaced by soda. The question arises whether the potash and soda from these two substances—both valuable materials—could not be economically obtained; and in certain cases this can be done. In certain porphyritic rocks these two species of felspar are found together. "Oligoclase" is another species, containing little potash, but much soda, and some lime; it derives its name from the fact that its cleavage does not produce right angles. The term "labradorite" is applied to still another species of felspar, which occurs abundantly in Labrador. Like the last two felspars, the crystals of labradorite belong to the anorthic system, or the system in which none of the three axles are at right angles. The crystals of labradorite present usually a grayish appearance, but when the light is seen reflected from them in a particular direction they show the most gorgeous colors, and at the same time a very delicate striation, which structure is intimately connected with the production of color. This labradorite is composed of a silicate of alumina, coupled with a silicate of lime, and a fair proportion of soda. Consequently, when the rocks of which labradorite is a chief constituent decompose, they give rise to soils rich in lime. If we look to the localities in which labrodorite occurs we shall find it is a very important material; it occurs abundantly in the basalt, augitic porphyries, and modern lavas of the Sandwich Islands, Iceland, Vesuvius, Etna, &c. And when these decompose, so far as to form soils, they often produce very rich soils indeed; and it is interesting to note that from soils thus formed in the vicinity of Vesuvius and Etna some of the most famous grapes and wines of the world are produced. "Anorthite" is a fifth species of felspar, and is so called from the fact that in the form of its crystals there is no right angle: it consists of a silicate of alumina and of lime, and occurs on a very small scale only. There is a question as to whether these are all distinct species of minerals, or whether some may not be merely mixtures of two or more species.

In the lavas of Mount Etna labradorite is very frequent, some of the more modern ones being composed almost entirely of labradorite and augite. And even in our own districts this mineral plays a very important part. The "whin sills" of the North of England, the great masses of dark igneous rock in the Dudley and Newcastle coal fields, and in the great tract which reaches from the Castle Hill at Edinburgh to the Castle of Dumbarton, these rocks, which are variously called plutonic, trappean, or volcanic, contain this felspar as a most important constituent.

And connected with the series of felspars there is the enormous economical importance of substances produced from some of them. In certain districts of Devon and Cornwall orthoclase occurs in a very soft and powdery condition. And about 100 years ago Mr. Cookworthy, an intelligent gentleman of Plymouth, and a Saxon chemist independently came to the conclusion that this kind of powder was the same material as the kaolin from which the Chinese manufacture their very best China. In England a pottery was established at Plymouth, and then Wedgwood and others took it up, and it has since become one of our staple branches of manufacture. From the discovery by the chemist alluded to sprung the famous Dresden manufacture. In the year 1800 the quantity of this so called Cornish clay exported from Cornwall was about 2,000 tons, in 1839 it had reached 7,600 tons, while last year the quantity was 108,000 tons. Another substance, known as China stone, was exported to the amount of 38,000 tons.

In Devonshire, on the east side of Dartmoor, is a deposit formed by nature of a clay very commonly called pipe-clay, of which 29,000 tons were produced; while if we pass still further eastward we find that a variety of clay, known as potters' clay, was exported from Poole to the amount of 65,000 tons, while 60,000 tons of the same material were exported from Devonshire. In fact, as a whole, 2,000,000 tons of these different varieties of clay are produced. And there is no doubt that, as in the case of kaolin, they are all produced from the decomposition of felspar.

STRENGTH OF IRON AND STEEL CONSTRUCTIONS—WITH CALCULATION OF DIMENSIONS.*

Translated from the German of "Weyrauch."

II.

PERCENTAGE OF CARBON, &C.

What is meant by the terms wrought-iron, steel, and cast-iron is more easily felt than explained; a definition, correct to-day, may not be so to-morrow. The latest authorities say that wrought-iron should contain about $\frac{2}{3}$, steel from $\frac{2}{3}$ to 2, and cast-iron more than 2 per cent. of carbon. But steel is to be found with $\frac{1}{4}$ and less per cent. carbon, and wrought-iron with about 1 per cent. Again, it is said that steel, but not wrought-iron, can be hardened; but steel with much phosphorus and little carbon cannot be hardened; wrought-iron, and even cast-iron, under certain conditions, may be made harder.

Greiner, Director of the Bessemer Works at Seraing, and Phillipart gave this definition of steel as contrasted with wrought-iron: "By steel is meant that kind of iron which can be obtained by fluid processes, and which, on account of its consequent homogeneity and compactness, is capable of offering a greater resistance; and which is also, because of the method of production, more uniform, both in composition and behavior." This would exclude many products from the category of steel.

Benedict's definition of cast-iron, correct in the main, is this: "By cast-iron is meant that obtained directly from ores, which does not admit of being wrought or welded; which melts at a lower temperature, and which contains the greatest proportion of carbon and foreign matter." Either one of the constituents of this definition alone is insufficient; *e. g.*, wrought-iron and steel can be got directly from the ore by Siemens' process.

Chemically pure iron has hitherto been obtained only in small quantity; it can be made very soft or very brittle, and is hard to melt. Iron becomes technically useful by combination with charcoal. This amounts to from 0.1 to 6 per cent., in part chemically combined, in part as graphite. With regard to the two sorts of metal which receive the names of wrought-iron and steel, it may be said that in either, the addition of carbon has an effect upon strength similar to that due to passing the elastic limit, or to mechanical treatment; the hardness and ultimate strength increase; while ductility and power of resistance to shock and sudden stresses beyond elastic limit diminish. This is less observable in wrought iron, because of the influence of other substances and of the mechanical treatment. But with steel there is a limit, beyond which the ultimate strength, at least for tension and compression, diminishes; and with this the ductility, so that the properties of the metal approach those of cast-iron. The position of this limit depends upon the presence of other elements, and the influences considered.

Knutt Styffe thought that he had found the maximum ultimate tensile resistance of iron and puddled steel at 0.8 per cent.: of Bessemer and Uchatius steel at 1.2 per cent. The latter agrees with the experiments of Vickers, in Sheffield, according to which the maximum is at 1.25 per cent. Karsten says that steel hardens best, and has most tensile resistance at from 1.0 to 1.5 per centage of carbon. With a greater percentage the hardness increases, but the

* Strength and Calculations of Dimensions of Iron and Steel Constructions, with reference to the latest Experiments. By J. J. Weyrauch, Ph.D. Four folding plates. New York: D. Van Nostrand.

resistance becomes less; at 1.75 per cent. all welding quality is lost; at 1.8 per cent. it works under the hammer with great difficulty; at 1.9 per cent. it can be worked no longer; and at 2 per cent. it has reached the boundaries between steel and cast-iron; it cannot be drawn out at red-heat without cracking and breaking under the hammer. Bauschinger has made some very interesting tests of Ternitzer Bessemer Steel. The test-pieces were made for the purpose, and were of the same sort, but contained different proportions of spiegeleisen. The results for ultimate resistance were as follows:

K, %	Tension.	Formula (9).	Compression.	Shearing.	Bending.
0.14	4,430	4,435	4,780	3,410	7,920
0.19	4,785	4,510	5,390	3,710	8,600
0.46	5,330	5,270	6,330	3,585	8,340
0.51	5,600	5,480	7,000	4,020	9,300
0.54	5,560	5,620	6,110	3,930	8,550
0.55	5,650	5,665	6,170	4,000	8,825
0.57	5,605	5,765	6,550	3,645	9,600
0.66	6,295	6,245	6,550	4,280	8,600
0.78	6,470	6,995	7,305	4,140	8,750
0.80	7,230	7,134	9,670	4,820	7,645
0.87	7,335	7,640	8,940	5,000	7,650
0.96	8,305	8,340	9,890	5,820	8,480

The elastic limit increased from 2,950 to 4,870; 2,775 to 5,000; 3,750 to 4,425. Setting off the tensile resistance as ordinates to the percentages of carbon as abscissas, a number of points marked by a cross is determined, grouped about a curve (I), of which the equation is

$$t=4,350\ (1+K^2) \qquad (9.)$$

in which K means the percentage of carbon. By means of this equation the values in the third column of the preceding table are found. The results of other tests are shown, notation as follows:

+ The results obtained by Vickers;
○ By Styffe, with hammered Swed. Bess. Hogbo round steel;
□ By Styffe, with rolled Swed. Carlsdal Bess. square steel;
○*u* By Styffe, from rolled Swed. Uchatius cast-steel, round, Wykmannshyttan;
○*k*. By Styffe, with soft hammered Krupp axle-steel;
□*t* Bauschinger, with rectangular tie-bars of Ternitzer Bes. steel;
○*t* By Bauschinger, with round rods of Bessemer steel.

This shows that formula (9) corresponds fairly, not only with Bauschinger's results, but generally with mean ultimate resistances; and that important deviations may occur from various causes. The equation

$$t=3,700\ (1+K^2) \qquad (10.)$$

which corresponds to curve II gives results, below which in general the ultimate resistance will not fall.

With respect to the results obtained for compression in the above table the following must be noted. Test rods from 3 by 3 by 9 cm. were strained between two compression plates. With the increase of load an S-formed curvature was observed, which increased more and more, till the prism suddenly sprung out. The strain on the fiber at the moment of springing is regarded as the ultimate resistance.

Bauschinger's tested pieces were of the form shown above.

The load was increased, and a pressure was reached without further increase, under which the prism contracted in length to less than half, while the transverse dimensions increased. The stress per square cm. at this limit, which Bauschinger regarded as the ultimate strength, increases with the percentage of carbon, from 9,250 to 17,800. On the other hand, the elastic limit was independent of the kind of test. Generally very short steel prisms may be loaded to double the amount permitted for tension.

Phosphorus, like carbon, increases the elastic limit, and ultimate tensile resistance, but diminishes the power of resistance to blows and to stress differences. It makes iron brittle, coarsely crystalline, and "cold-short," that is easily broken under cold working. For this and other reasons it cannot be used in bridge structures. Phosphorus affects steel still more unfavorably than iron. According to Greiner, steel, with from 0.2 to 0.25 per cent. of phosphorus, has too little strength for technical purposes. Phosphor-steel is best suited for rail-heads, because it resists wear; but the percentage of carbon should be diminished to prevent brittleness.

According to Sandberg and Turner, silica has the same effects as carbon, while Haswell, in the case of steel, with a certain proportion of phosphorus, ascribes it to a partial neutralization of the bad properties due to the latter. Slag helps phosphorus iron by diminishing its brittleness; but it makes it hard to work without splitting and springing. Next to phosphorus, sulphur is the most undesirable ingredient, having a like effect, except that it makes the metal particularly apt to break at red heat. Manganese, too, is a bad ingredient.

The effects of the above mixtures and others upon the strength of iron and steel are not clearly determined. Concerning their effect in the foundry information can be had from any text-book upon Metallurgy.

Whether, in a given case, steel or iron is to be preferred, depends upon considerations of resistance to special strains, of lightness, security under changes of temperature, economy, &c. In the application of steel, the proper percentage of carbon is dependent not only on the mechanical working it is to undergo, but also upon the composition of the ores and the method of production, because the proportion of other ingredients is determined by these. So Vickers recommends for pieces subjected to both tension and shock, 0.62 to 0.75 per cent.; Styffe, for axles of Swedish steel welded, or of one piece, 0.4 to 0.6; Greiner, for axles of Bessemer steel from Seraing, 0.3; Krupp, for locomotive and marine-engine axles, 0.5 to 0.6; for coach axles, 0.6; Greiner assigns for Seraing Bessemer steel, for chains and driving rods, 0.25 to 0.35; for tires not welded and piston-rods, 0.35 to 0.45; for steel rails, 0.4; for springs, 0.45.

INFLUENCE OF TEMPERATURE.

The influence of different temperatures upon the strength of steel and iron is not satisfactorily explained. With respect to ultimate resistance only, because of numerous experiments, has there been a growing accord of views. For most kinds of metal, especially for iron, the ultimate strength appears to increase with the decrease of temperature below zero, but also to reach a maximum at a little above 100 C. Within a certain interval near 16° the resistance is quite constant; the beginning and the rapidity of the increase and the position of the maximum are dependent upon the conditions already considered.

Fairbairn, in tension experiments with bar iron, found, in one case, the resistance at 0° equal to, in another, 1 per cent. higher than at 60°. Thurston found in torsion experiments a decided increase of strength to − 12°. Spence, in experiments in bending cast-iron, found at − 18°, a strength greater by about 3.5 per cent. than at + 15°. At higher temperatures, Fairbairn found for bolt iron the maximum of ultimate tensile strength at 163° 41 per cent. greater than at 18°; later experiments with bar iron put the maximum at 213°. A commission of the Franklin Institute, at Philadelphia, found the maximum strength 15 per cent. greater than its ordinary value at about 288°. Styffe has published the results of numerous experiments. See his Table VII.

Beyond the maximum the ultimate resistance decreases at first slowly, but very rapidly at red-heat. In this respect, too, the different kinds of metal behave very differently, and the diminution may possibly be the quicker and more rapid the lower the temperature of the metal when under mechanical treatment. Tensile resistance Fairbairn found to diminish from 202°, where it was about the same as at ordinary temperature, to a low red heat, by about 17 per cent.; up to ordinary red heat, by about 34 per cent. Experiments at the Franklin Institute found the ultimate tensile resistance, at 575° lowered by 0.66, and at 700° by 0.33 from the ordinary value. Bauschinger observed the strength of puddled plate, transverse to the direction of rolling, to be at red heat 780 kil. (2,700 ordinary), and of rolled iron along the fibers, 750 (4,430 ordinary).

These results are of importance with respect to constructions exposed to fire. Kirchweiger, of Hanover, regards the diminution of tensile strength by heating as the cause of boiler explosions; attempting to prove at the same time that a boiler filled with water may become red-hot. Bauschinger thinks it possible that the continual variation and differences of temperature of the outer and inner surfaces may diminish the cohesion of the laminæ of the plate; the inner laminæ bearing a disproportionate share of the strain, and the shearing resistance being lessened.

A frequent theme of discussion is the influence of cold upon resistance to sudden changes of stress,—shocks in particular. It cannot be denied that more axles and wheels break in winter than in summer. Styffe maintains that rupture is often due to the fact that the parts are held fast, and, therefore, cannot yield to the contracting influence of the cold: again, for tires, axles and rails, the effect of shocks is increased by the diminished elasticity of the ground.

Sandberg, in an appendix to the English translation of Styffe's work, maintains that these are not the principal causes of breaking. He laid iron rails upon granite supports which lay upon granite rocks, so that the elasticity of the foundations might be the same in any season. The two halves of these rails were tested by blows with a 380 kil. ball at − 12° in winter, and + 29° in summer; and it was found that at −12° the rail could withstand only $\frac{1}{3\frac{1}{9}}$ of what it could at + 29°. This showed, at least, that there are some kinds of iron that are weakened by frost. Styffe had tested only under dead loads, and in this respect his results were trustworthy.

Sandberg also found this peculiar result : that Aberdare rails, which bore in summer 20 per cent. more strain than those from Creusot, in winter had 30 per cent. less strength. This could be explained on the hypothesis of a difference in constitution which affected the strength unequally. Fairbairn had already shown the unfavorable effect of phosphorus and sulphur at low temperature; and Sandberg thought it possible that different results would have been reached had the metal been free from phosphorus.

Unfortunately the chemical constitution of the rails was not determined; but it seems likely, that phosphorus, which always diminishes resistance to shock, may operate more actively at a low temperature. Its effects also increases under high heat. Styffe found that the grain of a screw-bolt of phosphor iron was so affected, that a single blow of the hammer broke it: Steel, with increasing mixture of phosphorus, loses its capacity to undergo repeated heating without losing its peculiar properties.

In the year 1871, Joule, Fairbairn, Spence and Brockbank contributed to the Manchester Literary and Scientific Society four papers upon the influence of cold upon iron and steel. All agreed that resistance to dead load was not diminished by cold, but considerably increased. Brockbank held it certain that cold diminishes resistance to shock ; this, Joule and Fairbairn did not admit. All referred to experiments. No one will question the exactness of Joule's tests; but the test-pieces were wires, needles and nails, so that the results may not hold for larger pieces; while Fairbairn and Spence tested only under dead load. A series of observations by Brockbank confirm the results obtained by Sandberg. Rails were tested with blows; and in frosty weather they had far less strength than at ordinary temperature : a hollow cast-iron core-rod, about which a cylinder had been cast, cooled down to — 7½°, broke square and smooth, leaving a brittle-looking surface, while the pieces were made stiff and sound again by heating. A rod of round-iron of best quality, of 38 mm. diameter, which lay a week exposed to frost and was covered with ice, broke at 4½° under a single blow of a hammer weighing 5.4 kil.

All authorities admit the increase of resistance to tension under great cold, though they deny that there is a diminution of power to resist shocks. This is bad reasoning. It is certain that resistance to dead load is somewhat increased by frost; and besides this, according to Styffe, the elastic limit; just as in the case under hammering, rolling, hardening, &c.; but as with all the latter, resistance to shock increases, there seems to be no reason for a contrary judgment in the first case. Styffe has proved that iron becomes stiffer with decrease of temperature; agreeing with Sandberg.

Thurston concludes from results of his experiments that phosphorus and other substances, inducing cold brittleness, may impair resistance to shock at low temperatures, which seldom occur; and that in other cases resistance to dead load, as well as to shock, is increased by cold. This would be novel, but it must first be proven. Thurston's test-machine is well adapted to the lecture-room, being convenient and cheap; but it is not suitable for scientific experiments requiring results numerically exact. The velocity, an important element, is not regulated; the methods of measurement are much too primitive to answer to small differences due to temperature; and it is not to be taken for granted that torsion-tests are best suited to determine the properties of resistance of fibrous and laminated metals.

In a report of the Massachussetts Railroad Commissioners (1874), mentioned by Thurston, it is said, that "cold does not make iron and steel brittle and unsuitable for mechanical purposes, and that it is not the invariable rule that the most breakings occur on the coldest days." The membership of the Commission is not given, nor is it certain what kinds of metal were under consideration. Did it contain a large percentage of phosphorus? Were the rails iron or steel? It has been found in Northern climates—Canada, Sweden, and Russia—that a low steel, with $\frac{1}{3}$ to $\frac{1}{2}$ per cent. phosphorus, was affected by cold much less than iron. According to Styffe, there is no authentic case in which good steel contained more than 0.04 per cent. of phosphorus; though in one English iron rail there was 0.25 per cent., and in Dudley iron 0.35.

We draw the following conclusions from all the data at hand: (*a*) Iron and steel, which are entirely or nearly free from all foreign materials, have neither their resistance to dead load notably increased by cold, nor their resistance to shock diminished. (*b*.) Certain elements, not exactly determined, but phosphorus certainly, very much diminish resistance to shock and sudden change of stress. (*c*.) The question cannot be definitely settled until the chemical constitution is determined. (*d*.) Statistics of results in warm and cold latitudes, in summer and winter, after long frost, on days of sudden intensity of cold, are required.

The above has reference to the immediate influence of temperature. In regard to the effect of repeated changes of temperature, Wohler conjectures that frequent vibrations of molecules caused by heat, have the same effect in destroying cohesion as vibrations caused by external forces. Data from observation have not been obtained. Spangenberg, after examination of the fracture surfaces, did not adopt this hypothesis. Bauschinger, after testing boiler-iron, thought it possible that the strength of the plate was weakened by long action of the fire. But this decides nothing as to the effect of repeated influences. If Wohler's hypothesis is correct, we should recognize in change of temperature a cause of destruction, not only of metals, but also of all other solid bodies. And safety coefficients would be of no avail, but if we should make one beam twice as large as another, each half of the first would be as much affected as the whole of the second. In any case, bridges and buildings, which are subjected to only slight variations in temperature, will certainly be more likely to fail from other causes.

Bauschinger found the ultimate bending strength of steel, *i.e.*, the greatest fibre-tension at the instant of rupture, as given by the ordinary theory, always greater than the absolute tensile resistance. Wohler obtained a like result for wrought iron and steel; but the original strength was not less for bending than for pull. The experiments of Bauschinger and Styffe show that the modulus of elasticity for bending may be assumed as equal to that for tension, without great error. All these results show that the common theory of bending gives results accurate enough for practice. Of especial interest in this respect are Bauschinger's tests, in which the length of the gravity axis or elastic line remained unaltered by bending, and the original plane transverse sections remained perpendicular to it, even under very strong bending stresses.

Though it is not asserted that the method of calculation for very thin-walled plate-girders is exact in every respect; yet it is as sound as that for trusses, in which hinges are supposed, but rivets used; and it is safer than the ordinary method for compound trusses.

The modulus of elasticity of steel per square centimeter, is, according to

Bending tests by Kupffer, 2,124,990 (cast and file steel).

Pull and bending tests by Styffe, 2,412,300 (Bessemer steel).

Tensions tests by Bauschinger, 2,215,500
Compression tests by " 2,391,000
Bending tests by " 2,110,000
(Best steel prepared for test).

Crushing tests by Bauschinger, 2,082,500 (Best round rod).

Tension tests by Bauschinger, 2,310,000 (Best tires).

Bauschinger found the elastic modulus for torsion and shearing to be 862,000. From these results it follows that for steel we may assume as average :

For tension, compression and crushing $E, = 2,150,000$.

For shearing and torsion $E' = \frac{2}{5} E = 860,000$.

In experiments with English tire iron, bar iron and Swedish wrought iron, Kupffer gets a mean of 2,053,070; Styffe gives for good iron, with very little phosphorus 2,171,100; but for iron containing much phosphorus and slag, 1,930,600. The following figures are established for iron:

For tension, compression and crushing, $E=2,000,000$.

For shearing and torsion, $E'=\frac{2}{5} E = 800,000$.

No effect of carbon upon the elastic modulus could be observed; but with Styffe and Kupffer, it seemed to increase a little with the specific gravity and with lowering of temperature. Passing the elastic limit, and working in the cold condition, were found by Tresca and Styffe to cause a decrease.

According to Kupffer, hardening of hard steel decreases the elastic modulus by about 6.5 per cent.; but on the other hand Morin ascribes to cast steel a possible increase of E by hardening, by fifty per cent. By Wertheim's theory and Kirkaldy's tests, the specific gravity is somewhat diminished, if the metal is worked cold or in any way the elastic limit is passed, while the volume does not decrease, as has often been assumed. Yet all these influences are not so great and well determined that they require or permit a general review.

In calculations, the specific gravity of wrought iron may be put at 7.6 to 7.7, that of steel 7.8.

THE EXAMINATIONS OF METALS.

The higher the limit of elasticity, the greater the strain which a body will bear without permanent change of form. Raise this by hammering or hardening, and the body will be restored after greater strains; hence the extended use of springs. If the ordinary elastic limit served for all kinds of load, and if we were sure that it would never be exceeded, then it would be desirable to set the limit as high as possible for any construction. But the ordinary value is not sufficient in case of shock. In our riveted bridges, for example, local excesses may occur, because of unequally distributed strains. These are less dangerous, if the material is strong enough beyond this limit, so that a gradual change of form takes place, as in the case of a uniformly distributed force over the whole section.

The more extensible and tenacious the metal, the less risk in exceeding the elastic limit. It is well known that a very ductile and tough metal best resists shocks and sudden changes in stress. We should, therefore, judge of the fitness of metal, not only by the height of the elastic limit and the ultimate resistance, but also by its ductility and tenacity. The greater the latter qualities the greater the elongation before rupture.

When a rod is broken by a pull, there is a contraction of section at the breaking-point, beginning a little before rupture; attended by a decided elongation, which is independent of that which always occurs when the elastic limit is exceeded, and is approximately proportional to the length of the rod. As the total elongation at rupture is in part proportional to the length of the rod, in part independent of it, the ratio $\frac{\lambda}{l}$ of the total elongation to the length of the rod, can determine the ductility only in the case of rods of equal length; for the shorter the rod, the greater relatively the share of elongation at the point of rupture.

Kirkaldy, who has had the advantage of very many tests in this regard, recommends that we measure the excellence of the metal, both by its ultimate tensile resistance and by its contraction at the point of rupture. The stress at the breaking point, per square unit of the contracted part, increases with both the tension and the contraction; and the stress at this time furnishes the best means of determining the resistance. The results so obtained, arranged in order, give a trustworthy scale of values; but, if the gradation were according to ultimate strength only, very ordinary kinds might stand high in the scale. Kirkaldy found that the ultimate strength of coarse, crystalline metal, was equal to that of very tough and dense sorts.

The mechanical treatment and the method of production have their influence. So plate-iron is generally of less ultimate strength and ductility than round-iron.

The Department of Public Works, in India, has published the following table of requirements for estimate and supply, based on Kirkaldy's results. Contraction is expressed in per cent. of the original cross section:

	Class C.		Class D.		Class E.		Class F.		Class G.	
	t for Tension.	Cont.	Ten.	Cont.	Ten.	Cont.	Ten.	Cont.	Ten.	Cont.
Round and Square Iron..	4,250	45	4,092	35	3,937	30	3,775	25	3,620	20
Flat Bar-Iron	4,092	40	3,937	30	3,775	25	3,620	20	3,466	16
Angle and T Iron.......	3,937	30	3,775	22	3,620	18	3,466	15	3,300	12
Plate Longit............	3,755	20	3,620	15	3,466	12	3,300	10	3,150	8
Plate Trans.............	3,466	12	3,150	9	3,000	7	2,830	5	2,675	3
Plate; Mean	3,602	16	3,375	12	3,233	9.5	3,065	7.5	2,912	5.5

These figures show that we should use as much flat bar-iron as possible in our bridges for the parts under tension. Round-iron is useful in roof trusses.

In America, the conditions of proposals for bridges require high figures for ultimate strength (generally from 3,900 to 4,200 kil.); and test-bars must also stretch from ten to fifteen per cent. of their length before rupture. An elastic limit of from 1,600 to 1,750 kil., and uniformity of elastic modulus are prescribed. For example, in the case of the new Ohio bridge, no deviation of more than ten per cent. from the mean modulus of elasticity is allowed. Besides this, each piece under tensile strain is subjected to a test of twice the strain calculated for it—*i.e.*, about 1,400 kil. per square centr.—and, while under this strain, it receives a heavy blow from a hammer. It is generally thought in Europe that the Americans subject their bridges to a much greater strain than we; but for $b=700$, it amounts to about the same.

It is obvious that for the same ultimate strength the original strength increases with the extensibility, whether u is greater or less than the ordinary elastic limit. That the latter is possible follows from the fact that Tresca could push the elastic limit nearly up to t, and that permanent changes of form occurred below the elastic limit; and that in general the ordinary elastic limit has no influence upon many kinds of stresses. It is not impossible that at some time there will be found a sufficiently determinate relation between original strength and ultimate strength and contraction; or, between the ultimate strength and strain per square unit of the rupture-surface; or generally between u and values under dead load; so that u can be at least approximately found for each metal, and the numerical values be substituted in Launhardt's formula. And the vibration-strength s could be derived from some relation, or might be estimated Wohler found the rates $\frac{s}{u}$ nearly the same in metals so unlike as Phœnix iron and Krupp's cast-steel; the values being respectively $\frac{7}{12}$ and $\frac{8}{15}$. It would be desirable to make a great number of tests by bending, shock, &c., of metals for which the values of t, u, and s, have been fixed by numerous experiments. We should then have a better guide for the tests required of the manufacturers.

PERMISSIBLE STRAIN.

The values of the stresses having been calculated, the working strength a gives the stress per square unit, which can be maintained without rupture, under any number of repetitions. No reference is made to influences that do not admit of systematic investigation, such as shocks due to the passing of wagons in the streets, flaws, rust, &c.

A WROUGHT IRON.

Tension or Compression only.

For Phœnix axle-iron, Wohler's tests give $t=4{,}020$, $u=2{,}195$; and the working strength for bending

by formula I $\quad a=2{,}195\left(1+\frac{5}{6}\frac{\text{min. } B.}{\text{max. } B.}\right)$

Calculation must be made for the most unfavorable strain. For the same iron, under the ordinary strain, $u=2{,}195$, and $t=3{,}290$. This shows that such axle-iron is a metal which can hardly be suited for bridge-building. If no greater value is given, we put

$$\frac{t-u}{u}=\frac{3{,}290-2{,}195}{2{,}195}=\tfrac{1}{2},$$

and $\quad a=2{,}100\left(1+\frac{1}{2}\frac{\text{min. } B.}{\text{max. } B.}\right)$

Taking $\frac{1}{3}$ as safety co-efficient, the permissible strain per square meter,

$$b=700\left(1+\tfrac{1}{2}\frac{\text{min. } B.}{\text{max. } B.}\right) \qquad (11)$$

Alternating Strain.

For Phœnix iron, Wohler found $u=2{,}190$, $s=1{,}170$; hence

$$\frac{u-s}{S}=\tfrac{7}{15} \text{ and}$$

by formula II, if $\frac{1}{3}$ be the co-efficient of safety, we find in round numbers

$$b=700\left(1-\tfrac{1}{2}\frac{\text{max. } B'.}{\text{max. } B.}\right) \qquad (12)$$

Here max. $B >$ max. B'; both values numerical, without sign.

Special Cases.

For pieces continually under dead-load we find from (11), since min. $B=$max.B,

$$b=1{,}050 \text{ kil.}$$

For pieces always strained in one direction, then restored to strainless condition, since $B=0$,

$$b=700 \text{ kil.}$$

For bridge and roof girders, if p is the weight of structure, and q the total load, per running meter,

$$b=700\left(1+\tfrac{1}{2}\frac{p}{q}\right)$$

For parts in which maximum tension and compression are equal, $b=350$ kil., by (12).

B. STEEL.

Tension or Compression only.

For Krupp's cast steel, Wohler found $t=7{,}340$, $u=3{,}510$. Reducing the value of u somewhat, because the differences in strength of steel are considerable, and introducing the safety factor $\frac{1}{3}$;

$$\text{since } \frac{t-u}{u}=\tfrac{7}{6}$$

$$b=1{,}100\left(1+\tfrac{9}{11}\frac{\text{min. } B}{\text{max. } B}\right) \qquad (14)$$

This gives three-fold security if $t=6{,}000$ and $u=3{,}390$. This value of t by formula (9) answers to a steel of about 0.6 per cent. carbon, which is suited to bridges. Wohler found u for axle steel of Krupp, Bochum, Seebohm; and Krupp's plate steel between 3,300 and 3,500; for spring-steel, not hardened, of Mayr in Leoben and Krupp, 3,650. Of course the best material should be used for bridges, and it should not contain more than 0.03 per cent. of phosphorus.

Alternating Strains.

For the same cast axle-steel, Wohler found $s=2{,}050$; if $u=3{,}510$, say 3,300, and safety factor is $\frac{1}{3}$;

$$\text{since } \frac{u-s}{u}=\tfrac{5}{12}$$

$$b=1{,}100\left(1-\tfrac{5}{11}\frac{\text{max. } B'}{\text{max. } B}\right) \qquad (15)$$

This gives three-fold safety for $u=3{,}300$, below which value the original strength of steel did not fall in Wohler's experiments, and for $s=1{,}800$, while in Krupp, Borsig and Bochum axle steel the vibration-strength was about 2,000.

Special Cases.

For permanent strain under constant load (14) $b=2,000$ kil. For parts always strained in the same direction, then restored, $b=1,100$ (14) and (15). For bridge and roof girders, and generally for pieces for which

$$\text{min. } B \div \text{max. } B = \frac{p}{q}$$

$$b=1,100\left(1+\tfrac{9}{11}\frac{p}{q}\right)$$

For parts under equal max. tension and compression $b=600$ kil. (15).

C. REMARKS.

The safety factors, and permissible strains for steel and iron, have special reference to bridges and large structures. Hitherto the permissible strain for wrought-iron has been set at 700. But it is found that b, for wrought-iron, may vary between 350 and 1,050. The most favorable case is that of dead load, the most unfavorable that of alternating tension and compression. In this we see how variable are the figures required for the safety of the different parts of a structure. Hitherto much material has been wasted in building. It is of no avail to the general security of a structure to employ 700 in places where from 700 to 1,050 may be required, and then to employ 700 in a place where 350 is ample. If there is only one diagonal or vertical in a bridge, which suffers nearly equal strains of compression and tension, the security is only half as great as has been assumed up to the time of Wohler's investigations. It would certainly be wise to strengthen such exceptional weak points, and so strengthen the entire structure.

The above values of b, for wrought-iron, give three-fold security if $t=3,150$, $u=2,100$, $s=1,050$, Wohler puts 1,100 for permanent structures, in case of alternation of strained and strainless conditions, under tension only, or compression only; and 580 for equal tension and compression; the previous figures being 700 and 350. These correspond to a safety factor of $\frac{1}{2}$. For temporary structures, the values of u and s are greater than we have assumed in (3). For the present this will answer, by taking all values as given above, and selecting another safety factor, say one-half under favorable conditions.

We have not derived the value of b from Wohler's tests of Krupp's spring steel, because the values of u, s, and t are not all determined, and because the steel had properties which can be assumed only in exceptional cases. Softer and more extensible metal will always be used for bridges. If with this, the ultimate resistance diminishes, it does not follow that it does so in the same ratio as the original strength; for this depends also on the ductility. In the case of hardened spring steel, with diminishing t, $\frac{u}{t}=\frac{1}{2.50}$: for steel not hardened, $\frac{1}{2.20}$; for cast axle-steel, $\frac{1}{2.08}$; and for iron, $\frac{1}{1.83}$ to $\frac{1}{1.5}$.

Hence estimate of working strength depends upon this. For Krupp's spring-steel, Wohler's bending tests give

$$a=3,650\left(1+\tfrac{6}{5}\frac{\text{min. } B}{\text{max. } B}\right)$$

for the same hardened,

$$a=4,390\left(1+\tfrac{3}{2}\frac{\text{min. } B}{\text{max. } B}\right)$$

If very low steel is used for a bridge, the permissible strain must be less. For example, if only 0.45 per cent. carbon is desired, and a minimum ultimate strength of about 5,200 kil. is prescribed, (14) and (15) may be changed to

$$b=1,000\left(1+\tfrac{3}{4}\frac{\text{min. } B}{\text{max. } B}\right) \qquad (14a)$$

$$b=1,000\left(1-\tfrac{1}{2}\frac{\text{max. } B'}{\text{max. } B}\right) \qquad (15a)$$

These formulas for $t=5,200$, $u=3,000$, $s=1,500$ give three-fold security.

For the arch-bridge at the Champ de Mars, of Bessemer steel, the permissible stress for all parts, whether under tension or compression, was put at 1,000 kil. There are smaller cast-steel bridges in Holland and one of puddled-steel in Sweden. The most important is the bridge at St. Louis, over the Mississippi, which has a middle span of 158.5 m., and two end spans of 152.4 m. The advantages of steel are its greater security against intense cold and its lightness. The difference in expense will not long stand in the way, as the cost of steel is diminishing.

RECENT EXPERIMENTS IN THE FLOW OF WATER IN RIVERS AND CANALS.

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Translated from "Der Civilingenieur."

SINCE the publication of the great works of Humphreys and Abbot in America, and of Darcy and Bazin in France, the first containing the extensive hydrometric observations on the Mississippi, a giant stream with an extremely small slope, and the second giving very carefully made experiments in small artificial canals with large slopes, hydraulic literature has been mainly occupied in discussing and testing the laws developed by those authors and deducing from experiments empirical formulas for the flow of water in rivers and canals. The theory of Darcy and Bazin which introduces the irregularity of the river bed as an important factor has especially been received with favor, and has in Switzerland been further extended by Ganguillet and Kutter. Nevertheless, it must be confessed, that the formulae proposed rest on a very insecure theoretical foundation and can scarcely claim to be more valuable than mere interpolation formula. Since then even our greatest hydraulicians are more or less in a fog with reference to the flow of water in rivers and canals, and as the practical engineer is yet waiting for further experiments to enlighten his way, it may be proper and profitable for us to glance in review at the latest publications on this subject.

GERBENAU'S EXPERIMENTS ON THE RHINE.

The first book we notice* treats of the international hydraulic survey of the Rhine, originated by a congress of engineers from Switzerland, Baden, France and Bavaria, held at Basel on November 1, 1867. The observations resolved to be undertaken included not merely the measurement of the velocity and discharge of water, but the comparison of different methods and instruments under similar conditions. The experiments were to be made at high, mean and low water; systematic gauge readings were to be taken at different stations as far down the river as Mannheim, and also simultaneous observations of temperature and rainfall.

Unfortunately this programme was only partially carried out, so that the results obtained occupy but a small space when compared with the extensive labors of Humphreys and Abbot. The study of Gerbenau's book is, however, very profitable, for it gives a most thorough account of the experiments undertaken, and contains many important limits on hydraulic measurements.

At Basel where the Rhine makes a sharp bend from the east toward the north, having for a considerable distance a rocky bed, it was not easy to find a suitable place for the proposed experiments. The locality chosen—about 120 meters above the upper suspension bridge—was in a slight bend where the thread of the current coincided nearly with the middle of the stream, the bed being formed of cobble stones varying from five to sixteen pounds in weight. Besides the main section for experiments, there were two others, one above and the other below, all at right angles to the thread of the current, their distances apart being 70.65 meters on the right bank and 90 meters on the left. The area of the upper section was 438.011 square meters, of the middle or main section 426.152 and of the lower section 420.795, all taken at a reading of five feet on the Basel gauge. These sections were measured by help of a line extended across the river and supported by three boats, along which a fourth boat took soundings at distances of from three to six meters. The profile of the banks was also accurately determined. A gauge was established at each of the three sections in order to note the oscillations of the river. In spite of the advanced season (Nov. 5 to 14, 1867) the weather was favorable, the water low and but slightly subject to rise and fall.

The principal velocity measurements were made by a Woltmann's mill manu-

* H. Gerbenau. "Die internationale Rheinstrom-Messung bei Basel vorgenommen am 6-12 November, 1867." Munchen, 1873.

factured by Ertel & Son of Munich. The wheel which was 0.19 meters in diameter, had two arms, each 4.5 centimeters long, and 7.5 centimeters wide at the ends, making an angle of 45° with the axis. The mill was fastened to the end of an iron bar in such a way, that its axis when immersed in the water would assume the direction of the current. The observer stood upon a stage supported by two boats from the up-stream side of which he could place the mill at any depth in the water, while the boats were secured by anchors and their exact position noted by measurements made at fixed points on shore.

For the details of construction of the apparatus and the manner of conducting the experiments we must refer to Gerbenau's book. It is to be wished, however, that more exact information regarding the adjustment of the mill and the determination of its constant had been given. The author seems to be of the opinion that the ratio of the number of revolutions of the wheel to the velocity of water is constant; although his experiments in Germersheim harbor had shown that this ratio decreased from 0.6148 to 0.5263 as the velocity increased from 0.4 to 2 meters per second, he regards it as constant for greater velocities than two meters. Since the wheel made 190 revolutions in fifty seconds at a velocity of two meters, while in the Rhine measurements 250 revolutions in 50 seconds were recorded, further experiments certainly seem to have been required for the determination of this ratio. Moreover the formulæ deduced appear somewhat complex, and do not seem to have required the calculation of coefficients to four decimal places, since the velocity measurements cannot be accurately taken to a tenth of a millimeter. Each observation with the mill lasted two minutes and was repeated three or four times.

For the measurement of the surface velocity Gerbenau used floats also. These were in part wooden cubes of 0.3 meters on an edge, which would float entirely immersed, and in part short sticks immersed from 0.6 to 0.9 meters. Observations were taken in groups of 10 to 20, the floats being dropped from a boat stationed above the measuring sections, and their course for a distance of ninety meters determined by plane tables on shore. At a distance of forty-five meters on each side of the main section where the mill measurements were taken, secondary sections were established. Two observers in the line of these sections signaled the passage of each float, while a third noted the time on a watch beating seconds, and a fourth marked the point of passage on a plane table. The mean of the times for each group was taken and divided by the distance between the sections to obtain the mean velocity, which was considered as belonging to a point in the river corresponding with the mean of all the positions where the floats crossed the middle section.

It might be objected to this process that the mean velocity should be properly determined by finding the velocity of each float and taking the average of all the velocities; since, however, the distance traveled by each float could only be closely found by recording the point of passage over the middle section, the simpler method of the author gives, perhaps, results sufficiently accurate. It might, indeed, have been satisfactory enough if the point of passage over the middle section alone had been noted; for the manner used by the author in finding the path of the float can give accurate results only by exception.

With the Woltmann's mill surface velocity measurements were made at five points in the main section with the Basel gauge reading 5.625 feet, and at four points with a reading of 5.175 feet. With the floats nine groups of measurements were taken at a gauge reading of 4.85 feet. From these three surface velocity curves were drawn, from which by interpolation a curve of surface velocity for a gauge reading of five feet was deduced. The five points of the first series of observations are so distributed that they afford a pretty accurate construction of the curve, although a sixth point near the right bank is much to be desired. The second series contains only four points in the center of the stream, and even the third series is deficient in points near the banks. It is hence not possible to draw the curves with the requisite degree of accuracy, and particularly it appears doubtful whether the velocity at the banks can be taken at zero, as is here assumed to be the case.

It may also appear doubtful whether the float observations should be directly compared with those of the mill, since the first were made at a depth of 0.15 meters below the surface and give the mean of velocity of the water for a distance of forty-five meters on both sides of the main section, while the last were taken at a depth of 0.25 meters and in the main section itself.

Further observations with the mill were made at six points to determine velocities at different points below the surface. These were taken on different days and at different stages of the water. For each vertical the results were plotted and through the points the so-called parabola of vertical velocities drawn. The area of each curve divided by the depth of the water gave the mean velocity at each vertical; the position of this and its ratio to the surface velocity received extended discussion. The number and position of the observations at each of the six verticals is given by the following table:

No. of Vertical.	Distance from Left Bank.	Gauge Reading.	Depth of Water.	Depths at which Observations were taken.
1	7.30 meters	5.70 feet.	1.93 meters	0.25, 0.60, 1.12, and 1.67 meters.
2	54.27	5.12	2.85	0.25, 1.65 and 2.65.
3	79.98	4.70	2.65	0.25, 0.75, 1.54, 2.0 and 2.45.
4	82.90	4.55	2.60	0.25, 0.60, 1.50 and 2.30.
5	145.25	4.42	1.90	0.25, 1.10, 1.40 and 1.70.
6	173.98	4.67	1.39	0.25, 0.80 and 1.15.

The bottom velocities were determined by the graphical representation of the velocities observed at the above depths, and the surface velocities were regarded as equivalent to those taken at 0.25 meters below the surface. Since at a gauge reading of 4.55 meters, the breadth of the river was 200.1 meters, the vertical No. 6 was about 26 meters from the right bank.

As the experiments of Humphreys and Abbot, of Darcy and Bazin, and of Dupuit had indicated that the mean velocity in any vertical lay at a distance below the surface equal to 0.577 of the depth, Gerbenau took also a measurement at that point, and compared the observed velocity with the mean velocity deduced from the parabola, and found in general a very good accordance, for in the six verticals the observed velocity was 99.50, 99.85, 103.88, 104.45, 103.04, and 106.07 per cent. of the true computed mean.

The ratio of this mean velocity to the surface velocity varies between 0.7727 and 0.8525, being on the average 0.8226.

An investigation was also made to test the correctness of the formula given by Humphreys and Abbot for determining the mean velocity in any vertical from the greatest and least velocities. On this we shall not dwell as the determination in practice is of no value, since the bottom velocity, the greatest velocity and its position can only be determined by the construction of the parabola.

To determine the water discharge of the Rhine from the mean velocities found in the six verticals at different stages of the river, Gerbenau proposes the following method. He constructs the curve of mean velocity for a guage reading of five feet, divides the section into thirty-nine divisions, computes the area of each division, measures the ordinate of the curve at the center of each division and adds the products of each area by its ordinate. This process gives a discharge of 828.336 cubic meters per second.

In constructing the curve of mean velocity the number of ordinates was increased from six to ten by inserting middle ordinates between the first and second, second and third, etc., verticals. The computation of these middle ordinates depended upon the curve of surface velocities for a gauge reading of five feet and upon the coefficients found in the six verticals for the ratios of the mean sub-surface velocity to surface velocity. Since these coefficients range from 0.77 to 0.85, as above mentioned, the mean of the ratios for two adjacent verticals was used in interpolating the middle ordinate.

We have already intimated that the curve of surface velocities is not so well determined as we could have wished, and this inaccuracy influences of course the value deduced for the discharge. For practical purposes, however, the results have all desired accuracy. And if the methods followed in finding the mean velocity appear somewhat complex, we must remember that it would be scarcely possible to determine by a shorter process equally exact results from observations made on different days and at different stages of the river.

The mean velocity of the river as thus found was then compared with the maximum velocity, the ratio being 0.7305. The ratio of the mean of all the mean velocities in the six verticals to the mean velocity of the river was also found to be 0.928, agreeing with the value deduced by Humphreys and Abbot.

Besides the measurements of velocity, leveling observations were conducted to determine the slope of the river at the banks and in the thread of the current. These were made in different days and by different engineers, and exhibit somewhat large variations, as shown in the following table:

No.	Gauge Reading.	Fall of River in 24 hours.	Slope on Right Bank.	Slope on Left Bank.	Slope in Center of Stream.
1	5.58 feet.	0.135 meters	0.0011176	0.0009444	....
2	5.00	0.045	0.0011594	0.0010228	....
3	4.90	0.033	0.0012826	0.0013739	....
4	4.35	Stationary.	0.0022527	0.0011821	0.001218

By taking the arithmetical means of these results, Gerbenau concludes that the slope of the river when falling is 0.0011501 and when stationary 0.0012177, and regards it as probable that when rising its slope would be 0.0012853.

It may well be doubted whether this method of determining the slope is entirely satisfactory. The values given are deduced by dividing the difference of level of two points by their distance apart, which on the banks was 200 to 400 meters, and in the current 260 meters. It is evident, however, that the surface of the water for this distance is not a straight line joining the two points whose elevations were measured, but a broken line or a curve. If the slope is to be regarded as a straight line, it should not be deduced from merely the difference of level of the two end points, but intermediate points must be also considered. If the surface is really a curve, the proper slope would be the same as that of a tangent to the curve at its point of crossing the main section.

It may also be questioned whether in such cases the slope should be measured above the section where velocity observations are taken, or at the section itself. This and other questions, such as; how long a distance ought to be taken in measuring the slope; we shall discuss hereafter.

The leveling further showed that the surface of the water at the left bank was from 0.0367 to 0.1680 meters higher than at the right bank, and at the axis of the stream 0.0230 higher than at the left bank. The same peculiarity has also been observed by Siedler in his levels at Basel and by Gerbenau at Maximiliansau on the Rhine. It is evident then, that it is very difficult in rivers like the Rhine to find suitable places for experiments on the uniform motion of water.

Lastly, Gerbenau compares the results of his measurements with those deduced from the formulae of Chezy and Eytelwein, Humphreys and Abbot, Darcy and Bazin, Gaucher, Ganguillet and Kutter. His results were:

Surface breadth $=W=201.27$ meters.

Greatest depth $=D=2.785$ "

Wetted perimeter $=P=202.91$ "

Area of the section $=a=426.122$ square meters.

Mean radius $=R=\frac{a}{P}=2.1$ meters.

Slope in axis of stream $=J=0.0012177$.

Discharge per second $=Q=828.836$ cubic meters.

Greatest surface velocity $=C=2.630$ meters per second.

Mean velocity $=v=1.945$ meters per second.

The formula of Chezy and Eytelwein for the mean velocity is

$$v=50.93\sqrt{RJ}$$

and inserting for R and J the above values it gives $v=2.575$ meters, or 32 per cent. too much. The formula of Humphreys and Abbot,

$$v=7.825496\sqrt{\frac{a}{P+W}\sqrt{J}}$$

gives $v=1.501$ meters or 23 per cent. too little. Darcy and Bazin's formula,

$$v=\sqrt{\frac{R^2J}{0.00028R+0.00035}}$$

gives $v=2.393$ meters, or 23 per cent. too much. Gauckler's formula for slopes of more than 0.0007,

$$v=5.35\sqrt[3]{R}\sqrt[4]{J}$$

gives $v=1.638$ meters, or 16 per cent. too little. Lastly, the formula of Ganguillet and Kutter,

$$v=\sqrt{RJ}\left\{\frac{23+\frac{1}{n}+\frac{0.00155}{J}}{1+\left(23+\frac{0.00155}{J}\right)\frac{n}{\sqrt{R}}}\right\}$$

gives (when n is taken as 0.03) $v=1.9387$ meters, which agrees very closely with the observed mean velocity.

The first of the above formulae appears the poorest, and the last the best in the light of the Basel observations. The agreement in the last case depends, indeed, somewhat upon the lucky choice of the co-efficient n, whose values varies from 0.022 to 0.035.

Besides the main investigations, described above, experiments were also instituted *to compare the accuracy of various hydrometers*, of which a brief account may be interesting.

By comparing the surface velocities as deduced from the observations by Woltmann's mill and the floats, it appeared that the values resulting from the latter were slightly greater. This may, perhaps, be accounted for by supposing that the float which was immersed to a depth of 0.3 meters acquired the velocity of a thread of water at a depth of 0.15 meters, while the mill noted the velocity at a depth of 0.25 meters. Cubic floats 0.3 meters thick, and cylinders 0.1 meters in diameter, gave the same velocities when immersed equal depths. On the other hand, gypsum plates 1.2 meters long, 3 centimeters wide, and 7.5 millimeters thick, gave, when floating on their flat sides, velocities slightly less than their cubic blocks.

These results can only be regarded as approximate on account of the difficulty of determining the exact path traversed by the float. Gerbenau rightly claims however that in taking float measurements the path should be tolerably long and a large number of observations be taken, since in nearly half of his experiments the probable error in noting the time of passage was 0.5 seconds, and in about a quarter of them an entire second.

Unfortunately no experiments with double floats were made, and this is a matter of great importance, since the use of double floats in large rivers can scarcely be avoided while their accuracy is still open to some suspicion.

Woltmann's mill was also compared with two of Pitot's tubes constructed according to Darcy's plan, one manufactured by Bridell and Lanicca, and the other by Salleron. By four observations with the mill, at a depth of 0.25 meters a velocity of 2.1668 meters per second was recorded. By the tube made by Salleron, ten observations showing on the average a difference of head of 34.115 centimeters gave from the formula

$$v=0.84\sqrt{2g(h-h_1)}$$

a velocity of 2.1732 meters, and by the other tube with a mean difference of head of 30.57 centimeters the velocity was 2.0572 meters. The agreement between the mill and the tubes is hence very satisfactory, although the second tube was not properly adjusted.

The differences of head measured by Salleron's tube in the ten observations range from 32.3 to 38.7 centimeters, being 94.7 to 113.4 per cent. of the mean, which correspond to variations of 97.3 to 106.5 per cent. from the mean velocity. This indicates that sufficiently accurate results with the tube can only be obtained by taking a large number of observations.

A second Woltmann's mill was also tried, which had a recording wheel eight to ten centimeters in diameter enclosed in a cylinder, with four arms curved in a helical form, and the comparison of its results with those of the first mill was most satisfactory. The first instrument made by Ertel gave a velocity less than one per cent. smaller, a deviation not surprising, for the area of its wheel was double that of the second. Gerbenau endeavors to determine from the differences between the single observations the accuracy of these mills, and he shows that the mean error of that made by Ertel is only half as great as for the second and concludes that large mills are to be preferred for experiments in rivers. Although the number of his observations is too small to prove this conclusion, we feel disposed to regard it as correct.

Lastly Gerbenau gives an account of some measurements made by Legler on Nov. 6, 1867, at the upper suspension bridge at Basel 180 meters from the section of the international observations, and with the gauge at 5.7 feet. Only floats were used; there were thin sticks of about nine square centimeters loaded at the lower end so as to float in a vertical position, and thus give the mean velocity of the immersed portion. The path was only thirty meters long, and the floats passed over it in from eight to thirty-one seconds. Observations were made at twenty-nine points in the cross section with usually three floats for each point. For the surface velocities Gypsum floats 1.2 meters long were employed. These as also the sticks appear to have been too light, the latter rarely retaining their vertical position. On drawing the curve of velocities, a very irregular broken line was obtained, such as could not be expected in a cross section so regular and it is hence not surprising that the ratio of the greatest velocity to the mean velocity was entirely different from that deduced by Gerbenau, and that the discharge found was thirty per cent. greater. This shows what great care must be observed in executing such experiments; in particular the floats must have a longer path than was here employed, and precautions must be taken that they preserve their vertical position and reach nearly to the bottom. Even if these sources of errors be avoided, it remains doubtful if such floats actually give the mean velocity in the vertical, and it is much to be wished that this question might be soon decided by careful experiment.

The above extended review will be sufficient to indicate the many interesting problems discussed in Gerbenau's book, and if all have not been solved we are yet thankful that so much light has been thrown upon them, and we can heartily recommend to every engineer the perusal of the work itself.

HARLACHER'S EXPERIMENTS ON THE ELBE.

In the next book which we take up,* Prof. Harlacher, of the Polytechnicum at Prag, gives a short introduction on Hydrography in general, and that of Bohemia in particular, and then discusses at great length the observations made on the Elbe for determining its discharge.

The locality of the experiments was near the boundary of Saxony and Bohemia, about 650 meters below the village Herrnskretschen. At this village a brook joins with the Elbe, and below it at the locality chosen the river is enclosed by retaining walls, and is but slightly curved, its breadth at a normal stage of water being 118 meters, and the greatest depth three meters.

Harlacher used in his measurements a Woltmann's mill, made by Amsler and Laffon, and he gives a beautiful lithographic plate, illustrating the details of its construction. The wheel was sixty-five millimeters in diameter, with two blades fastened to short arms. These blades were of a screw-formed-shape, 44 millimeters long in the direction of a radius, and 90 millimeters wide on the exterior circumference. The arrangement for engaging and disengaging the gear was particularly neat; if not in gear a simple pull on a string brought it into action; if in gear a pull on the same string disengaged it. In many forms of Woltmann's mill, the observer must keep a strong tension on the string to hold it in gear, and such errors are, perhaps, introduced from the action of the water on the string. In Harlacher's machine, the string was enclosed in a tube. Extra arrangements were also introduced to keep the axis of the mill in the direction of the current.

To ascertain the constant of this mill

* A. R. Harlacher. "Beiträge zur Hydrographie des Königreichs Bohmen." Prag, 1872-3-4. Originally printed in the Journal "Technische Blätter."

experiments were made in the still water of Podol harbor. Carried by a boat it was moved at different velocities through the water for a distance of 105.26 meters, the time varying from 41 to 162 seconds, so that the velocity ranged from 0.65 to 2.56 meters, the wheel making from 2.42 to 9.60 revolutions per second. The results of these experiments were represented graphically, the number of revolutions in thirty seconds being taken on the abscissa unit and the corresponding velocity per second as the ordinate unit, the points thus found furnishing a curve, which coincided very closely with a straight line drawn from the origin of co-ordinates. From this curve the velocity corresponding to any number of revolutions in thirty seconds could be seen at a glance, and used in the other graphic computations.

The first measurement was made on April 12, 1871. A gauge was established on the right bank, and the measurement of the velocities and of the cross section carried on simultaneously. As no line could be stretched across the stream, signals were established on shore by which a boat could place itself in the section, where its position was noted by a plane table on shore. Observations were made at nine places in the section, and at several points in each vertical. The first vertical at a distance of 1.4 meters from the left bank afforded only one measurement at a depth of 0.35 meters below the surface; the second at 13.8 meters from the left bank had three at depths of 0.1, 0.8 and 1.5 meters; and so on to the ninth vertical which was 114.57 meters from the left and 5.84 meters from the right bank. It is not mentioned whether each velocity measurement was repeated, and owing to the short time employed in the work, such repetition could hardly be expected.

In considering the working up of these measurements, the graphical method employed deserves particular attention.

If we imagine at each point of a cross section of a river, a line drawn perpendicular to the plane of the section representing the velocity of the thread at that point, we obtain a solid whose volume corresponds to the discharge of the stream. From velocity measurements taken at various points in the section, we may construct this solid, by erecting normals whose length are equal to the observed velocities, and through their extremities passing a surface. The cubic contents of this solid may then be determined by intersecting this solid with horizontal planes, finding the areas of the surfaces thus cut out, and from these areas and the vertical distances between the surfaces computing the volumes of the small prismatic volumes whose sum is that of the solid.

Harlacher applied then the following construction to determine the discharge per second. From the velocity measurements made in each vertical the corresponding velocity parabolas were drawn. Now if at distances of 0.25, 0.50, 0.75, etc. meters, parallels be drawn to the verticals representing the depth of water they will cut the velocity parabolas at the points corresponding to velocities of 0.25, 0.50, 0.75, etc. meters. If all the points at which the same velocity obtains be united, curves will be obtained similar to the contour curves used in computing the contents of hills. The areas of these curves may be measured with the planimeter and used, according to well known methods, in finding the cubic contents.

If these constructions are to be made easily and accurately, observations must have been made at many verticals, and at many points in each vertical. The discharge is, however, much more exactly determined than by using the mean velocity in a vertical as found from the parabola of vertical velocities, and multiplying these mean velocities into the corresponding vertical areas of the cross section.

Harlacher obtained the following as results of his measurements:

Discharge per second $= Q = 281$ cubic meters.

Area of the section $= F = 252.4$ square meters.

Mean velocity per second $= v = 1.11$ meters.

Mean surface velocity $= 1.35$ meters.

Ratio of mean to greatest velocity $= 0.73$.

Ratio of mean surface velocity to mean velocity $= 1.27$.

It is interesting to note that the value of the ratio of the mean velocity to the greatest surface velocity is the same as that found by Gerbenau.

Besides these measurements the slope of the Elbe was also investigated. From a point on the left bank 114 meters above the section to the section itself, a slope of 0.000395 was found; from the section to a point 95 meters below the slope was 0.000210. On the right (the concave) bank for distances of 76 and 152 meters above the section, the slopes 0.000263 and 0.000395 were found, and from the section to a point 76 meters below the slope 0.000312. The points leveled were plotted and tangents drawn to the point of intersection with the section, from which it was seen that the tangents were parallel although the one on the right bank was three centimeters higher than that on the left. The slope shown by the tangents was 0.000315, while the mean slopes of the upper portion was 0.000399 and of the lower 0.000333.

Prof. Harlacher compares the results of his measurements with those of a great number of formulæ, by inserting his values for slope, area of section, wetted perimeter, etc., in the expressions for mean velocity. The comparison shows that Eytelwein's formula gives a result seventeen per cent. too large, Humphreys and Abbot's seven per cent. too small, Darcy and Bazin's nine per cent. too large, Gauckler's fifty-two per cent. too large, Hageni's eighteen per cent. too large, Bornemann's three per cent. too small and Ganguillet-Kutter's eight per cent. too large. A single experiment like this is, however, not sufficient to decide concerning the generality of a formula, and hence but little value can be attached to this comparison.

The remarks of the author concerning such experiments and the manifold sources of error which affect them are worthy of attentive consideration. As sources of error the following are mentioned : inaccuracy in the measurement of depths particularly in deep rivers with rocky beds ; errors in measuring the breadth of the stream, errors in determining the constant of the Woltmann's mill, in fixing the position of its axis, in noting the time, and in throwing the machine out of gear, inaccuracy in reading the number of revolutions, and lastly, disturbance due to impurities in the water. Moreover the accurate determination of the slope is of great influence, in which errors may be committed as high as twenty per cent. of the true value, partly by the agitation of the water level and partly by the sources of error peculiar to leveling. Considering the number and the great influence of these errors, it can scarcely surprise us that no formula has yet been found which can be used in all cases with security.

The above experiments are described in the first part of the book published in 1872. The second part published in 1873 contains an account of more extended experiments to which the preceding may be regarded as a preparation. These were carried on at the same place and in the same general manner, but many improvements were introduced by which more accurate results were obtained. The mill observations were taken from a stage supported by two boats, the time was noted by a watch marking seconds accurately, the positions were located by a theodolite instead of a plane table, the duration of each measurement was sixty instead of thirty seconds, the cross section was determined by four surveys of thirty-seven soundings each, and the Woltmann's mill was adjusted anew.

In finding the slope the greatest care was also taken; the levels extended over 150 meters above and below the section, and points were taken on the water surface at every thirty meters. The heights were plotted on the natural scale, and the distances on a scale of $\frac{1}{1000}$, and through the point where the curve, thus obtained, cut the central section a tangent was drawn as representing the slope. It is remarkable that the slope 0.000315 was found for high, mean and low water stages, the same value as determined in the survey of the previous year.

During the first observations the water surface stood at 2.05 meters below an assumed zero point of reference, and nearly the same as in the survey of 1871; the discharge per second was found 270 instead of 281 cubic meters. During the second set of observations the surface was 2.49 and in the third 3.06 meters below the zero point.

The velocities observed at different points in the verticals, were used in constructing the so-called parabolas of vertical velocities, nine of which were drawn from the first set of observations, ten from the second, and nine again from the third. These curves showed that the greater velocity in a vertical was sometimes at the surface and sometimes below the surface; and that it appeared to be lower as the stage of water diminished; further, that the mean velocity of a single vertical obtained by dividing the area of the parabola by the depth of water was at mean high water from 0.58 to 0.67, at mean water 0.50 to 0.67, and at low water from 0.54 to 0.62 of the depth below the surface; and, lastly, that the bottom velocity was from 19 to 60 per cent. of the surface velocity, or from 22 to 76 per cent. of the mean velocity.

These relations are readily exhibited to the eye by the graphical constructions, which give the three profiles to an exaggerated scale, and the velocity curves. The curves of mean velocities in the single verticals, of maximum velocities and of mean velocities in the whole stream are drawn upon the cross-section, with also curves added showing the surface and the bottom velocities. Three tables are given in which the relations between these quantities are exhibited numerically, and from which we make the following extract:

	High Water.	Mean Water.	Low Water.
Area of section in square meters	245.40	192.00	119.30
Mean velocity in meters per second	1.10	0.95	0.76
Discharge in cubic meters per second	270.00	182.30	90.80
Greatest velocity in the section	1.48	1.30	1.12
Mean surface velocity	1.27	1.10	0.85
Greatest surface velocity	1.42	1.27	1.11
Mean bottom velocity	0.57	0.44	0.38
Ratio of mean velocity to maximum velocity	0.74	0.73	0.68
Ratio of mean velocity to mean surface velocity	0.87	0.86	0.90
Ratio of mean velocity to mean bottom velocity	1.93	2.16	2.00
Ratio of mean velocity to greatest surface velocity	0.77	0.75	0.69
Ratio of mean velocity to mean depth	0.55	0.59	0.67

This table is very valuable, showing as it does that the different velocities are not related to each other in a constant manner, and also that, for the depths at which they are found no general formula can be obtained.

If now it be required from these three measurements to find the discharge at other stages of water, it can within certain limits be obtained by an easy graphical construction. As, however, the area of the section for different stages can be quite accurately determined and the discharge is the product of the area by the mean velocity, Herlacher undertakes to find an interpolation formula for the latter, none of the formulæ thus far published being regarded as sufficiently accurate. He proposes that the mean velocity be regarded as a function of an unknown power of the mean radius and the slope, and seeks to calculate this power from his observations which offers but little difficulty since the slope at all stages of water was found the same.

Accordingly in the equation

$$v = \beta r^x$$

only the coefficient β and the exponent x are to be determined, and from the three observations,

$v=0.76$ and $r=1.13$ at low water

$v=0.95$ and $r=1.60$ at mean water

$v=1.10$ and $r=2.01$ at low water

he finds for x the corresponding values, 0.642, 0.642 and 0.643, and for β the values 0.7026, 0.7026, 0.7026, so that the formula becomes

$$v=0.7026\ r^{0.642}$$

A comparison of the results computed from this and other formulae shows that at low water many of them give nearly the same values, but that at high water the differences are quite marked. The curve computed from the above expression for v lies between those given by the formulae of Darcy and Bazin and of Ganguillet and Kutter, as also between those from the formulae of Humphreys and Abbot and of Gerbenau, is, in fact, nearly a mean between them. Nevertheless, the new formula can only be accepted with circumspection since the assumption that the fall of the river at all stages of water is the same, as found by the Elbe observations, can scarcely be entertained without further experimental proof. It is possible, indeed, that at the place of observation on the Elbe, the slope would have been found different from 0.000315 for very high or very low stages of water.

As already remarked, Herlacher deduced the above formula only for the purpose of computing the discharge through the section at Herrnskretschen for different stages of water. For this computation continuous readings by a self registering gauge would have been much better. As none, however, were taken, the gauge observation at Tetschen and Schandau were used to find by interpolation the simultaneous stage of water at the intermediate measuring station. For this a series of corresponding gauge readings at Herrnskretschen, as well as at Tetschen and Schandau was of course necessary since the water level at these three points does not equally rise and fall. The interpolation was made graphically by laying off the water stage at the section as ordinate, and that at Tetschen or Schandau as abscissas, and connecting the corresponding points from which a curve representing the variation of water at the section for the last six months of 1871 was obtained. From this it was seen that the mean reading (below the assumed zero point) was 2.84 meters, while that at Tetschen was 0.33 and at Schandau 1.22 meters. The highest water which occurred in July 8, was 1.47 meters above the mean, the lowest on Dec. 7 was 0.68 meters below.

For each stage of water the mean velocity can now be computed from the formula

$$v=0.7026r^{0.642},$$

since the corresponding cross section can be constructed and the mean radius $r=\frac{F}{p}$ easily found. The discharge is then simply $Q=Fv$. Representing the various values of Q by ordinates to a straight line where abscissas are the times, a curve is obtained whose areas represent the discharge for any required time intervals.

Such a curve was constructed by Harlacher and the areas measured by the planimeter. He found the discharge to be

In July...........639,317,000 cubic meters.
August.........359,917,000
September......196,727,000
October........305,230,000
November.....221,391,000
December......334,459,000

The mean discharge is then 11 million cubic meters daily, or 130 per second. The least daily discharge 3689000 on Dec. 7, and the greatest 36858000 on July 8.

Taking the monthly discharges and determining from them the stage of water, we obtain nearly the same values as by taking the arithmetical mean of all the observed stages; thus:

	July.	August.	September	October.	November	December.
Mean discharge per second.	238.7	134.4	75.9	114.0	85.4	124.9
Corresponding water stages	−2.20	−2.27	−3.18	−2.90	−3.11	−2.83
Observed mean stage......	−2.22	−2.77	−3.18	−2.91	−3.11	−2.87

The sign — prefixed to the water stage shows that the surface of the water lay below the zero point of reference.

Here closes the second part of Harlacher's contribution to the Hydrography of Bohemia, a work distinguished for its elegant graphical constructions, and which may be well taken as a pattern in the execution of hydrometric experiments. Could such experiments be made on all our great streams an interest in technical circles, equal to that excited by the measurement of the arc of a meridian in Central Europe, might be awakened, and as so much time and money have been spent on the latter, it is possible that governments might be induced to furnish the necessary means for the execution of comprehensive hydrographic surveys, if engineers would only take the initiative in proposing it.

In the third part of his work Herlacher treats of the discharge of the Elbe in the first six months of 1872, according to the same plan as before. He regards it as well to begin the hydrographic year with July, and to end it with the following June, since the influence of the winter snows is the better included.

Since in this period no new measurements were undertaken, the discharge was computed on the supposition that the slope of the river remained 0.000315 even at higher water stages (which renders the results somewhat questionable) by finding the mean velocity from the formula

$$v = 0.7026 \left(\frac{F}{p}\right)^{0.642}$$

The results are given in the following table:

	January.	February.	March.	April.	May.	June.
Mean discharge per second.	190.	166.	343.	299.	348.	221.
Corresponding water stages.	−2.45	−2.58	−1.70	−1.90	−1.68	−2.29
Observed mean stage......	−2.46	−2.62	−1.77	−1.93	−1.91	−2.35

We see here again that the mean of all the observed water stages does not exactly correspond with the stage of water as deduced from the mean discharge. For the entire half year the discharge is 262 cubic meters per second, or nearly double of that of the preceding half year. The differences between the smallest (43 and 113) discharges and the greatest (429 and 2485), are still more striking.

Considering this discharge with reference to the water shed of the Elbe above the section of Herrnskretchen, which has an area of 50,600 square kilometers, it apappears that in the second half of 1871 there were discharged 40,600, and in the first half of 1872, 81,500 cubic meters per square kilometer, which, for the whole year, from July, 1871, to June, 1872, is only 25 per cent. of the rainfall.

Particularly interesting in this third part is the account of a sudden flood in the river, arising from a local storm near Beraun in May, 1872, in which gauge readings at 38 stations, over a distance of 836 kilometers, were taken. In this investigation, not merely the actual gauge readings, but the differences between the readings during the flood and those immediately before, are properly discussed. The curves which represent these changes at 24 stations between Prag and Hamburg, from May 25 to June 8, 1872, give a clear picture of the course of the high water, arising from a local rain near the head of the river. It decreases in height steadily as it descends the stream, while its width increases; in the upper river it rises quickly and remains but a short time at its maximum height, in the lower, however, rising slower and lasting longer,—exhibiting the characteristics of a great wave; even in Hamburg its influence was perceptible on the gauge readings. The 215 kilometers from Prag to Dresden were passed over in 34 hours, the 378 kilometers from Prag to Wittenberg in 88 hours, and the 794 kilometers from Prag to Hamburg in 240 hours, showing that its velocity decreased as it neared the sea.

The high water arising from the melting of the winter snows flows somewhat differently, since it receives from all sides constant accessions. We should here expect that the high water would continually increase as it descends the stream. This is not exactly so, as Harlacher shows, for the form of the river bed exerts considerable influence. In the Elbe the spring floods increased in depth only to Tetschen, below which they again decreased. The summer floods appear to follow a slightly different law, as is seen from a single example discussed.

GORDON'S EXPERIMENTS ON THE IRRAWADDY.

The works noticed above are of a decidedly practical character touching the theoretical side of the subject only in connection with the measurements made by their authors. In the two brochures of Mr. Gordon* we have, however, a

* Robert Gordon. "Fragment containing a discussion of a new Formula for the flow of water in open channels." Milan, 1873.

theoretical decision of the laws of flowing water, his extensive hydraulic observations being only incidentally mentioned. The first which he moderately calls a "Fragment" was printed for private circulation, and comes before us with no pretensions to offering anything new even in theoretical hydraulics.

It opens with a justifiable complaint concerning the numerous formulae for the motion of water in rivers, formulae containing so many different constants raised to so many different powers and leading to results so widely varying, all of which seem to be only empirical and which are hence changed by every new series of experiments. It then investigates the reason of the failure of previous efforts to establish a general valid formula, points out that this lies not so much in the imperfections of the observations as in the inaccuracy of the fundamental theoretical conceptions, subjects these conceptions to a searching examination and closes with a proposed new formula.

All the theories on the subject hitherto set up appear to the author to be founded on the three conceptions of Castelli, Torricelli and Dubuat. In the beginning of the seventeenth century Castelli announced that the velocity of the water in a river would be doubled if its depth were doubled; that the velocity of a thread of water increases proportionally to the pressure or head so that the so called vertical velocity scale is a triangle whose vertex is at the surface and base at the bottom of the river. This last was modified by one of his pupils, Cavaliere, by considerig that the upper layers of water must be carried along with the lower ones so that the velocity scale would be the triangle reversed.

Torricelli demolished Castelli's hypothesis by carefully conducted experiments, and showed that here the same law exists as in the free fall of a body. Starting with this more correct conception, Guglielmini originated the first actual theory of the motion of water in rivers. He said, that in this motion the same law prevailed as in the descent of a body on an inclined plane. On account of the mobility of the single particles of water a river varies in cross section as its velocity changes. The acceleration or retardation of the single molecules is communicated to neighboring molecules, but in diminished proportion with the distance. The resistance of the bottom destroys the acceleration due to the inclination. If the motion is permanent the stream retains the velocity previously acquired, which is the greater the greater the slope. On account of the variation in the resistance, permanent motion seldom is found in streams; rivers with a bed of boulders are in a continually changing condition of acceleration and retardation. Since the upper layers press upon the lower ones, the motion of the stream depends not merely on the slope, but also on this pressure; near the head of the river where the slope is large the velocity is due mostly to the slope, lower where the slope is small the head of water enters as a disturbing cause, and in every section of the stream the velocity of the lower layer will be determined more by the head, and that of the upper layers more by the slope.

In consequence of the influence of the pressure, the velocities in a vertical would follow a parabolic scale; this can rarely be true in fact, since the resistance at the bottom is much greater than at the surface.

These views found acceptance till the time of Dubuat, although Couplet's experiments in the water pipe at Versailles showed that it was impossible that the velocity could increase as the square root of the head. Dubuat, however, stated the principle, which to-day is regarded correct, that the surface slope is to be considered as the only cause of the motion of water in rivers. This leads to the conclusion that if the influence of the resistance were absent all the molecules in a section must have the same velocity, since the motion of a single molecule depends only on the difference of pressure, exerted by the preceding and following molecules, and since this difference is equal for all points of the section.

Gordon regarded the theory of Guglielmini as preferable to that of Dubuat, and he endeavors in his Fragment to demonstrate this, and to deduce a new formula for the motion of water in rivers, having previously given a critical review of the various formulæ hitherto proposed.

* Robert Gordon. "On the Theory of the flow of water in open channels." Rangoon, 1875.

As these formulæ have but little more than an empirical value, we shall not dwell upon Gordon's discussion.

In deducing the new formula the method followed is long and not sufficiently clear, and we pass it over to give the result obtained, noticing that the author confesses at the end of his investigation that it does not correspond to experimental results, but that one member must be divided by the $\frac{3}{2}$ power of the slope to make an accordance. It will be sufficient to give his formula and the experimental verification. The formula is:

$$PWD = \left(\alpha + \frac{\beta W \rho^2}{R^2 \sqrt{D}}\right) p \rho V^2$$

in which the letters have the following significations:

P = depth at which the center of pressure of the section lies.

W = breadth of stream.

D = slope.

R = mean radius.

p = wetted perimeter.

V = mean velocity.

ρ = coefficient of roughness.

α and β are constants to be determined.

Gordon then gives a plate in which five series of Bazin's experiments, viz., those on canals lined with smooth cement, with boards, with bricks, with small and with large pebbles, are represented according to Bazin's corresponding five formulæ and according to the new formula, the values of α and β being taken at $\alpha = 0.000112$ and $\beta = 0.00000007$, while according to the degree of roughness, ρ takes the values 1.00, 1.36, 1.47, 2.46 and 3.30. In Bazin's experiments the constant slope 0.0049 was employed; Gordon, however, gives seven series of experiments with board canals having slopes of 0.00824 and 0.00208, and these, as also the former, agreed closely with the new formula.

Gordon also compares the results of his experiments at Irrawaddy, which we shall describe below, with his new formula, and finds a satisfactory agreement when the coefficient of roughness ρ is placed at 2.23. The following table contains in *English measures* the principal data of these experiments:

Date in 1872.	Gauge Reading.	Daily rise (+) or fall (—).	Slope multiplied by 10,000.	Cross Section A.	Discharge Q.	Mean Velocity V.	Wetted Perimeter p.	Width at Surface W.
Aug. 20	36.00	—.	0,947	223,516	1,442,007	6.451	5220	5020
" 23	33.75	+0.25	0.933	212,403	1,212,190	5.706	5215	5008
Oct. 18	32.25	+1.09	0.925	204,988	1,148,790	5.604	5212	5002
Sept. 9	31.83	—0.50	0.925	202,921	1,098,288	5.365	5208	5000
" 29	29.75	+1.00	0.918	193,083	985,959	5.106	5205	4992
" 21	26.58	+0.92	0.911	177,123	871,823	4.922	5196	4990
Nov. 4	24.08	+1.00	0.905	164,633	757,132	4.599	5191	4975
Oct. 30	23.91	—1.25	0.905	163,313	712,125	4.360	5190	4974
Nov. 2	22.08	—0.25	0.898	154,750	667,268	4.228	5185	4968
" 8	22.08	—1.08	0.898	154,750	627,925	4.057	5185	4968
" 12	17.75	—1.17	0.884	133,363	483,477	3.626	5160	4942
" 14	15.75	—1.00	0.887	123,483	416,139	3.370	5150	4928
" 16	14.33	—0.75	0.871	116,649	370,072	3.258	5140	4915
" 21	12.08	—0.42	0.864	105,353	307,256	2,767	5020	4770

In the following table the last column is added by the reviewer, and shows that $\frac{PWD}{pV^2}$ is very well represented by $\left(\alpha + \beta \frac{W\rho^2}{R^2\sqrt{D}}\right)\rho$ when the values $\alpha = 0.0000774$, $\beta = 0.00000012$, $\rho = 2.23$, are given to the coefficients. Other values for these coefficients than those found by Bazin for his small canal are hence necessary, although it is not to be denied that the formula agrees very well with the experiments. The table is given in *French measures*, the values of p, W and V being repeated:

Date in 1872.	p	W.	R.	P.	V.	$\frac{PWD}{pV^2}$	$\frac{W}{R^2\sqrt{D}}$	Computed value of $\frac{PWD}{pV^2}$
Aug. 20	1591	1530	13.047	11.098	1.965	0.000262	923	0.000288
" 23	1589	1526	12.410	10.428	1.739	309	1026	303
Oct. 18	1588	1524	11.984	10.197	1.708	309	1103	313
Sept. 9	1588	1523	11.872	10.117	1.635	334	1124	316
" 29	1585	1521	11.303	9.872	1.556	354	1242	331
" 21	1583	1520	10.386	9.217	1.500	346	1476	363
Nov. 4	1582	1516	9.663	8.821	1.401	378	1707	393
Oct. 30	1581	1516	9.588	8.792	1.329	413	1733	397
Nov. 2	1580	1514	9.094	8.532	1.288	426	1932	423
" 8	1580	1514	9.094	7.861	1.236	438	1932	423
" 12	1572	1506	7.875	7.589	1.105	509	2582	510
" 14	1569	1502	7.034	7.589	1.027	560	3012	567
" 16	1566	1498	6.915	7.359	0.993	567	3356	623
" 21	1530	1460	6.393	7.039	0.843	0.000731	3995	0.000698

Gordon gives also the following account of these extensive experiments. They were undertaken to determine the loss of water by leakage through the dykes which had been built for a great length in the delta on the right bank of the Irrawaddy River. At the head of the delta, near Saiktha, and also 110 miles below, near Zaloon, measurements were made in the same manner as those of Humphreys and Abbot on the Mississippi ; viz. surface velocities were observed about sixty times a day by double floats, whose lower point was one meter below the surface. Ten series of observations were also made daily on velocities at greater depths, the position of the lower float being placed one meter deeper each time till it touched the bottom. The arithmetical mean of these velocities was taken, and the ratio between this mean and the mean surface velocity in the same vertical was found, by whose help the mean velocity in a vertical for each observed surface velocity was found. The river which, at Saiktha, is over 1,500 meters wide, and at high water 23 meters deep, was divided into ten divisions, and the discharge was found by multiplying the area of each division by the mean of the mean velocities of the verticals contained in that division.

The determination of the slope was particularly difficult. From the levels extending over about eighteen miriameters in length a slope at high water of six inches per mile (0.000095) was found. At Myanoung (22.5 kilometers from Saiktha and 320 kilometers from the ocean), the high water level lies 23.16 meters above the mean sea level and the low water level 10.97 meters, giving a variation of 12.19 meters. At Saiktha from high to low water there is 12.8 meters, at Henzadah (120 kilometers south of Myanoung) 11 meters, and at Zaloon 10.5 meters difference in level. The different stages of water, hence change the above given slope considerably; the difficulty is also increased by the sandy bottom of the river which retards the flow at low water. At high water the stream takes moreover a shorter course than at low, so that the slope at low water is reduced to four and two inches per mile.

Under these difficulties it was scarcely possible to find the slope corresponding to each observation, and Gordon thinks that only for the gauge readings from 14 to 36 feet was it determined for a distance of 16 kilometers with sufficient accuracy.

For the computation of the depth P at which the center of pressure of the section was located the formula

$$P = \frac{\int x^2 y dx}{\int x y dx}$$

was used, in which y is the breadth for any depth x and dx is an increment of two feet.

From these experiments, which are not further described in Gordon's pamphlet, it is only possible for him to explain why it happens that the formulæ based upon Dubuat's theory give in general extremely satisfactory results. According to his views, this lies in the fact that the values of P and R in many cases are very nearly equal, and he gives as proof the following data from the Irrawaddy survey:

Gauge reading=	36.0,	29.8,	24.1,	17.7,	12.1,	6.0,	1.9.
R =	43.6,	38 0,	32.3,	26.4,	21.3,	20.2,	19 3.
P =	35.7,	32.4,	29.0,	25.8,	23.1,	20.1,	18.2.

Since the numerical values of P and R are so nearly equal, the numerical values of the quantities $\frac{PWD}{pV^2}$ and $\frac{RD}{V^2}$ come also nearly equal, and in these quantities lies the characteristic difference between the new formula and the old ones.

The second work whose title we have given above is a supplement to the preceding, containing more complete information concerning the extensive hydraulic measurements, whose results had incited Gordon to deduce a new formula for the motion of water in rivers.

As already mentioned the experiments were conducted on the same plan as those of Humphreys and Abbot. The Mississippi observations however were confined to observations in 254 verticals, while those at Irrawaddy were carried on continually from Aug. 1, 1872, to Sept. 1, 1873, (Sundays excepted), so that velocity curves for 7000 verticals were obtained.

For the velocity observations the so-called double float was used. This consisted of a light wooden disk, 25 millimeters in thickness, and 152 millimeters in diameter, which floated on the surface, and to which was attached by a cord the lower float—a wooden cylinder 305 millimeters long, and 152 thick, so loaded that the upper disk remained only 6 millimeters above the water surface. The cord was 1.6 millimeters in thickness and was varnished, its length being so arranged that the lower float was always either 1, or 2, or 3, etc., meters below the surface; the velocities at these depths were observed in succession, and the irregular movement and frequent immersion of the upper one showed when the bottom was reached, although a greater velocity was here often observed (remarkable to relate) than at less depths. These floats were numbered and were, as ordered, dropped in regular succession from an anchored boat lying far above the place of observation, their passage across two established lines (60.95 meters apart) being noted by theodolites and chronometers on shore. Velocity curves for 10 verticals were daily thus determined, and by 30 to 60 measurements at a depth of 1 meter, a curve of surface velocities also daily established. Any change among the observers was carefully avoided, and exact compliance with the instructions was required. The observers, moreover, were unacquainted with the theoretical aim of the investigation. During the time of observation there was one low and two high water periods. The principal section was near Saiktha at the head of the delta; and since the number of measurements was too great to allow of immediate reduction only those made in 3000 verticals at Saiktha were subject to computation.

From the velocity measurements made in the verticals at every meter in depth the vertical velocity curves were constructed, and a comparison of the curves for different stages of water affords a view of the changes produced by changes in the level of water. The irregularities disappear when many curves under similar conditions of gauge reading, depth of water and distance from the bank, are combined. Hence Gordon selects a limited number of such curves for each division of the cross-section, and combines them to obtain a mean curve. This was done for different stages of water and thus about 2000 curves were found which, in Feb. 1874, were communicated to Bazin, who still further studied them and combined all those found at low water, as also those for high water. In this way 500 reduced curves resulted, which represent indeed a wonderful industry.

In the Irrawaddy River the guage reading at the highest water is 40 feet, but in the years 1872 and 1873 it only reached 36 feet. The lowest known low water is 2 feet below zero, but in 1873 it did not quite reach this limit. Bazin hence considered two low water stages, from 0 to 3 feet, and from 3 to 5 feet, as also two high water stages from 22 to 30, and from 30 to 36 feet gauge reading. He divided the section for low water into four, and for high water into six divisions and grouped all observations of verticals of equal depth in a division together, viz., from 17 feet in depth to 70 feet. Since, however, the absolute distances did not allow a strict comparison, he divided the resulting mean depths for each group into ten equal parts and computed the corresponding velocities and from their values constructed the vertical velocity curve for each vertical. From these mean vertical velocity curves for both low and high water stages were found, so that finally only four curves remained, in which, of course, the individualities of the original curves have disappeared. In the book the complete numerical data are given in order that any one may construct the original curves for himself; we think it, however, a pity that they were not worked up according to Prof. Harlacher's method.

By comparing this enormous number of vertical velocity curves, Gordon finds (and it is also easily seen from the figures in his work) that for a constant gauge reading the ratio of the velocity at any depth to the surface velocity increases as the depth of the vertical increases; and that for the same point of the cross section. This ratio is considerably greater at high than at low water. While at low water the surface velocity is always perceptibly greater than the velocity below the surface (excepting, perhaps, in the deepest places), the difference of the velocities in different depths of the same vertical decreases more and more as the water rises, until in the greatest depths of sixty to eighty feet the greatest velocity occurs near the bottom of the river. This remarkable phenomenon was established not only in the section at Saiktha, but also in a section 140 kilometers below.

It may now be asked whether the phenomenon here brought to light is to be regarded as a universal law as Gordon supposes, or whether it was only produced by some local influence which modified the law as given by the parabola of vertical velocities. The sand banks in the Irrawaddy, which are so numerous as to be dangerous to navigation, may be regarded as such a local cause, even if the great distance (sixteen miles) of the nearest bank below Saiktha would seem to forbid such assumption. The slope of the river is indeed extremely small (0.000095) so that a bank of considerable height, which would be dangerous to ships drawing 1.2 meters, would be perceptibly higher than the bottom of the river at Saiktha. Unfortunately, a satisfactory view of the question is not to be had, because thorough levels of the river bottom and surface are not communicated; and hence the results of Gordon's extensive experiments are only to be accepted with great circumspection. Special levels were here, if any where, certainly necessary, in order to render useful experiments carried on with so great energy. It is also to be wished that a longer path for the floats had been employed, and that the number of floats used for the determination of the surface velocity (30 to 60 on a width of 1000 to 2130 meters), as also the number of verticals for velocities below the surface (10) had been greater, particularly in the wider places. Gordon's experiments, however, inspire a far greater confidence than those of Humphreys and Abbot, for Hagen has shown that it is extremely probable that their results were altered in part to establish the theory proposed. His velocity measurements are also free from the suspicion attaching to theirs, for his lower float was connected with the upper by a very small cord, while in the Mississippi Survey the surface of the cord for measurements at a depth of 100 feet was $1\frac{1}{2}$ times as great as that of the float itself. Against the use of double floats there is little to be objected, since the comparative observations at Basel show them to be not untrustworthy. Other experimenters have also observed the phenomenon that the velocity decreases below the surface without being able to point out a sufficient cause for its occurrence. Although the new theory needs further tests, Gordon's observations are worthy of great attention, and his publications are certainly to be reckoned with the most interesting of late times in this department of literature.

REVIEW AND COMPARISON.

Arrived at the end of our report, we allow ourselves to take a backward glance at those points which need to be particularly observed in future hydrometric experiments. Whenever possible measurements of velocity should only be made with a carefully adjusted Woltmann's mill of suitable size, and each measurement should be at least once repeated, the time never being less than one minute. In wide and deep rivers where the mill cannot be used the so-called double float should be employed. The size of the float should correspond to that of the stream, and if possible ought to be spherical and so loaded that the cord should not be too slack; the accuracy of this instrument is, however, not yet satisfactorily proved. Particularly important is the length of the path over which the float passes; it should be long enough so that the time of passage of the greatest velocity may be about one minute. The course of the float ought to be observed, and such rejected as deviate from a straight line parallel to the current. Lastly, it is advisable to allow many floats to pass at each point, in order to obtain the mean time of passage.

It is self evident that a hydraulic survey will be the more accurate, according as more simultaneous velocity measurements are taken at different points of the cross section.

In working up the observations, the method proposed by Prof. Harlacher yields the most comprehensive and the most accurate results: if, however, the experiments are carried on at different times, Gerbenau's method of interpolation is to be recommended. Graphical representations prevent gross errors, and permit all the relations to be more clearly seen than in mere numerical work.

If such experiments are to be used in investigating the law of the flow of water in rivers, as great care must be taken in the choice of the places for observation, and in the determination of the slope and the cross section, as in the execution of the velocity measurements. Unfortunately a considerable diversity of opinion exists as to what should be regarded as the slope, and it may be hence recommended to make accurate levelings on both banks, and in the current for a length of five times the breadth of the stream and to draw them on profile paper, from which the total slope as also the local slope in the cross section may be easily seen.

Considering, however, that in general, in great rivers especially, a permanent motion of the water is scarcely to be expected, it appears more correct to carry on such experiments in the following manner, pointed out several years ago by Weisbach:

Let two cross sections be taken at a sufficient distance apart, and let their areas F_0 and F_1, their wetted perimeters p_0 and p_1, and the mean velocities v_0 and v_1 be determined, as also the total fall h and the distance l between them. Then from the relation

$$h=\frac{v_1^2-v_0^2}{2g}+z\frac{l}{2}\left(\frac{p_0 v_0^2}{2gF_0}+\frac{p_1 v_1^2}{2gF_1}\right)$$

the coefficient of resistance z may be found. The greater labor arising in this method may perhaps be out-weighed by the greater value of the results obtained. The two sections, which under a permanent motion of the water will give equal discharges, furnish a proof whether the place chosen is suitable for such experiments, while the uncertainty in regard to what is to be considered the proper slope disappears.

THE RESISTANCE OF VESSELS.

From "Engineering."

Of all the abstruse subjects connected with naval architecture, that which has hitherto been most involved in mystery, and has most successfully defied all attempts to unravel its subtle intricacies, is unquestionably the subject of resistances. Marine propulsion in most of its branches has indeed, until within the last few years, been almost a sealed book even to the most able investigators; and the absence of definite knowledge and of exact reasoning based upon sound principles and correct data, has naturally favored the growth of erroneous doctrines and given a fictitious importance to formulæ equally erroneous in principle, although offering at least some assistance to the naval architect. The old Admiralty formula

$$S^3 = \frac{C \times IHP}{D^{\frac{2}{3}}} \text{ and } S^3 = \frac{C_t \times IHP}{A}$$

the more modern formula of Professor Rankine, and the various theories on resistance put forward by Mr. Scott Russell, and many others advanced from time to time, are all doomed to vanish before the light that Mr. Froude is gradually throwing on the subject. He conquers the subject a bit at a time, but his progress is sure, and each fresh step, while it shows how far abroad everybody has been up to the present, shows also more clearly than ever that Mr. Froude is on the right track, and encourages us to hope that he will soon reach a complete and satisfactory solution of the puzzling phenomena which surround the movements of a ship through the water.

An enormous stride was made when Mr. Froude discovered the relation which exists between the resistance of ships and their models. Having found the "corresponding speeds" at which the resistance of ships and their models would be proportional to their displacements, a new era was commenced, because for the first time it became possible to argue safely from the results of experiments with models to the performances of ships. Following this up he has shown that the area of midship section, as such, plays but a very unimportant part in the resistance of ships instead of occupying as it has hitherto done the most prominent position. The idea that as the area of midship section measures the area of the canal that the ship digs, as it were, for herself through the water, it must be the chief measure of her resistance, is certainly a most plausible and taking one, and although Mr. Froude has shown it to be utterly fallacious, yet we doubt not it will be clung to by many for some time to come. The point to which Mr. Froude has dovoted himself this year at the meetings of the Institution of Naval Architects is the effect on the resistance of adding to the length of straight middle-body in ships. And the results are most valuable and instructive, for they throw an entirely new light on the subject of resistances, and account for many strange results that have appeared anomalous and perplexing, whether looked at from a practical or scientific point of view. It was for a long time thought that adding to the length of the straight middle-body could not affect the resistance. Since the important part played by skin friction in the resistance of ships became recognized, however, it has been conceded that the effect of adding to the length of the straight middle-body would be to materially increase the resistance, owing to the increased resistances due to skin friction, and it has been shown very conclusively that better results might be obtained under some circumstances, by a somewhat broader ship with finer ends of the same displacement, and having no straight middle-body. There can be little doubt that a great bar to the acceptance of these ideas by shipowners and shipbuilders has existed, owing to the very favorable results found to arise, within the last few years, in not one ship or two ships, or a dozen ships, but in scores of steamers, by cutting them amidships and lengthening them by the addition of a piece of straight middle body. We have heard instance after instance quoted where the vessel has carried more cargo, steamed faster, and burnt less coal after being lengthened, and in fact vessels have been converted from unprofitable to profitable ships by the simple process of lengthening. Where great improvements have been made in the engines and boilers at the time of lengthening the ship, such as when they have been "compounded," it would be only natural to expect better results than formerly, and to combine less coal consumption with greater cargo capacity. Where little or no change had been made in the machinery, and yet coal consumption and speed were said to have remained as well as before, or even better, with a greater skin resistance and greater weight of cargo—and we have often heard such facts asserted firmly by people in a position to know the truth—the question became not a little perplexing, especially in view of other somewhat similar cases of lengthening in which a loss of speed of nearly half a knot had been the result.

Mr. Froude's paper supplies a curious and valuable explanation of such apparent anomalies. His experiments were made with models of ships varying in length from 180 feet to 500 feet long, all having the same beam 38.4 feet, the same draught 14.4 feet, the same form of mid-ship section, and the same length of fore-body and after-body, or entrance and run, viz., 80 feet each. The shortest ship had no middle-body, and the longest had 340 feet length of straight middle-body. The intermediate vessels went in steps of about 20 feet of middle-body, everything else remaining the same; in fact the shorter models were made from the longer, by cutting out successive lengths of middle-body and rejoining, so as to keep the same surface friction. The displacements of the ships represented by the models ranged from 1,245 tons to about 6,000 tons by intervals of about 142 tons.

The resistance of each model at different speeds was ascertained, and the corresponding resistances of the series of ships were set up in the usual form of "curves of resistances." These curves proved to be by no means fair curves, such as one would expect on the supposition that the resistance varied as the square or any other power of the speed, but presented undulations—"humps or contrary flexures." And instead of the resistance in each case going up regularly as the middle-body was lengthened, a curious alternation of excesses and diminutions of resistance was observable.

"Comparing together the curves of resistance of these ships, we find that at the lower speeds every added 40 feet of length (and 142 tons of displacement) increases the resistance by about the same amount; but at the higher speeds this harmony disappears. At 13 knots, for example, the 200-feet ship makes considerably more resistance than the 240-feet ship, which has 568 tons more displacement; and though at 14½ knots the longer ship again makes the greater resistance, yet even at 14 knots the 280-feet ship makes less resistance than both the 200-feet ship of 1,137 tons less displacement, and than the 240-ton ship of 568 tons less displacement; and at 14½ knots the 200-feet ship makes almost as much resistance as the 360-feet ship of 2,275 tons more displacement. Similar anomalies appear in the comparison between other ships. The tendency to alternate excesses and defects of resistance in the shorter ship as compared with the longer appears throughout the diagram."

Mr. Froude then proceeds to analyse these results, regarding the resistance of a ship as made up of three items, viz., skin friction, eddy-making resistance, and wave-making resistance. The former is approximately proportional to the area of skin, so that addition of successive equal increments of parallel side can only affect it to the extent of producing corresponding equal increments for every additional length. "The anomalies we have noticed," says Mr. Froude, "can only be the result of some unexpected effect which the distance between the two ends produces upon the other two items which make up what may be conveniently termed the 'residuary resistance.'" Mr. Froude then eliminates the known fractional resistances from the total resistances given on the curves, and makes a fresh series of curves, the abscissae being the lengths of straight middle-body for the respective ship and the ordinates being the "residuary resistances" for the corresponding ship at the several rates of speed. A series of curves are thus formed, one above the other, for different speeds, each curve representing the gradual change in "residuary resistance" corresponding to the gradual elongation of the middle-body at a particular speed. From these curves it is seen "that up to a speed of about eleven knots they are straight and level, showing that the residuary resistance is practically unchanged by insertion of parallel side; but that at higher speeds they present a series of regular undulations, showing that the gradual insertion of parallel side produces an alternate increase and diminution in the residuary resistance."

These undulations in the curves of residuary resistance explain and harmonize with the apparent anomalies in the comparison of the curves of resistance before referred to, but how are they to be accounted for? This question has fortunately not been left unanswered by Mr. Froude. By carefully observing the waves formed along the side of the model corresponding to the 500 feet ship, when running at a speed corresponding to 14.3 knots, the positions of the crests and hollows were ascertained, and it was found that a close connection existed between the positions of those crests and hollows, and the positions of maxima and minima formed by the undulations on the curves of residuary resistance. It became, in fact, clear "that the residuary resistance is smallest when the middle-body is of such a length as to place the middle point of the after-body where a wave crest would be if the middle-body were continued, and largest when of such length as to place it where a trough would be. The inference is, that according as a wave crest or a wave hollow comes about the middle of the after-body so will the forward pressures of the water on the after-body be greater or less, and the total resistance of the ship be less or greater. In the very long parallel-sided form, 500 feet, the sternmost of the train of waves left by the bow had become so small that its effect on the stern was almost insensible, and the united resistance was due to the generation of a separate wave system by each end of the ship. "As we gradually reduce the length of middle-body the stern is brought within reach of waves large enough to produce a sensible effect, and according as it is brought into conjunction with a crest or a hollow, the total wave-making resistance becomes alternately less or greater than that due to the sum of the actions of the two ends of the ship when acting independently; the wave-making resistance becoming least of all (except at the very highest speed) when the middle-body is reduced to nothing."

Mr. Froude points out that the length spacing of the wave system, and consequently the positions of the troughs and crests, depends on the speed, and therefore the position of the after-body, which is specially favorable at some given speed, may be specially unfavorable at a higher speed, and at a higher speed still may be favorable again.

The models experimented upon by Mr. Froude had fine entrances and runs, and this may account for the fact that the undulations in the curves of residuary resistances did not become important until comparatively high speeds were reached. Probably in ships having ends as full as an ordinary cargo-carrying merchant steamer, they arise at much lower speeds, and these phenomena must always exert a very considerable influence upon the behaviour of such vessels before and after being lengthened.

No part of the question of resistances possesses a more direct interest for shipowners than this, and we most heartily congratulate them and Mr. Froude upon the progress that has been made in our knowledge of the subject.

THE TRANSPORT OF "CLEOPATRA'S NEEDLE." *

By Mr. JOHN DIXON, C.E.

From "The Builder."

The obelisk known as "Cleopatra's Needle" is of great historical interest, because it had sculptured upon it the history of the man who quarried it from the old quarries of Syene (the modern Assouan), and the reason why he quarried it. There were few monuments extant, so far as we know, which could, like this, date back 3,400 years. In addition to its historical interest, however, the obelisk in question was of interest to engineers, in consideration of the means which were resorted to in order to quarry and transport in safety such huge monoliths. Cleopatra's Needle was not alone among obelisks, and possessed no peculiar features. In point of size, it stood only about eighth or ninth on the list of obelisks with which we were acquainted. The largest of which we knew was the Lateran Obelisk in Rome, which was brought by the Romans, with about twenty smaller ones, from Egypt, as the most curious objects they could lay hold of to decorate their imperial city. The Lateran Obelisk had a height of some-

* A paper read before the Civil and Mechanical Engineers' Society.

thing like ninety feet, and was ten feet six inches square at the base, whereas Cleopatra's Needle was only sixty-nine feet three inches high, with a base of seven feet square. Ten years ago, when the lecturer was in Egypt, his attention was especially directed to this obelisk, which he saw lying in the sand on the shore at Alexandria. He dug around it and under it for the purpose of examining it, and it appeared to be little the worse for wear except that two of its sides were somewhat weatherworn, and did not retain the polish which still existed on the other two sides. Nevertheless, the hieroglyphic inscriptions were quite distinct enough to be read by the learned in those matters, and it therefore retained its history as clearly as on the day when it was set up by Thothmes III., *circa* 1400 B.C. Egypt in those days was the leading country of the world, not only in arts and commerce, but in learning and science, and to her great university of Heliopolis came Strabo, Pliny, Herodotus, and others. Thothmes went to the old quarries of Syene for the material of his obelisks. From these quarries for generations before him the Egyptians had been accustomed to sculpture those great blocks of granite which even to this day were our wonder and admiration. The granite of Syene was micaceous and somewhat coarse in texture and pinkish in color, and in the quarries, to the present day, there existed an obelisk, half cut out, much larger than any other we knew of. That obelisk, if it had ever been completely quarried and set up, would have been ninety-six feet high and about eleven feet square at the base. The proportion of height of these obelisks to the square of base was generally about ten to one, or, in other words, the height was about ten times the square of the base. The hieroglyphics on "Cleopatra's Needle" were from two feet to three feet long, cut two inches deep and three inches or four inches broad, so that they could be read from a distance of fifty or sixty yards. The inscription, besides recording the virtues and power of Thothmes, recorded that the obelisk when set up was tipped with gold. This feature was of course gone, but there was a slight ledge round the point at the top which was no doubt made to receive a gold tip, or one of bronze gilt. On the top of the obelisk of Luxor at Paris, which the French brought from Egypt, there was a similar ledge or groove. The inscription on Cleopatra's Needle did not say in what city that obelisk was set up. Some accounts had it that it was first erected at Thebes, and was afterwards removed by Ramesis to Memphis. Be that as it might, it was ultimately removed to the ancient city of Heliopolis. The site of that city, once the Oxford and Cambridge of the world, and at that time, it may be presumed, covered with magnificent buildings, now presented one of the most astounding spectacles which could be witnessed. Nothing remained but a green plain, in the center of which was a solitary obelisk, opposite to which once stood the stone now known as "Cleopatra's Needle." The latter was subsequently removed to Alexandria. How it came to be thrown down in its present position nobody knew. It had been conjectured that an earthquake was the cause of its overthrow, but it was much more likely, Mr. Dixon thought, that it was thrown down to get at the bronze tortoises on which it was believed all these obelisks were placed. In 1798 the French conquered Egypt, and they laid their hands on everything that was valuable or invaluable in the country. They carried off an enormous quantity of Egyptian remains, and they proposed to carry off the Rosetta stone (now in the British Museum), Cleopatra's Needle, and other antiquities. Before they could do so, however, they were driven out of Egypt by the English, and at the conclusion of that brilliant campaign, in which Sir Ralph Abercrombie fell, a great effort was made to secure Cleopatra's Needle, which would when erected in London, form a fitting monument of one of the most brilliant campaigns in which English arms had ever been engaged. The army subscribed four or five days' pay, and, assisted by the navy, took steps to remove the obelisk. They had hardly commenced, however, ere the red-tape and pipeclay of those days sent forth an order to desist in the attempt, as such work would be destructive of discipline and of the accoutrements of the men. So the obelisk remained where it was. When Mehemet Ali assumed the reins of power, he, wishing to please George III, presented the Rosetta stone and many of the principal objects in the Egyptian Court of the British Museum, together with Cleopatra's Needle, to the English nation. The British Government, however, had always declined meddling with this obelisk, although repeatedly urged to bring it over. The expense involved was made the great obstacle, although even so utilitarian a man as Joseph Hume proposed to spend the national money in bringing over the obelisk, and contended that the money would be well spent for such an object. The cost of bringing over the obelisk has been estimated in years gone by at £100,000, but Mr. Dixon said he was confident that the cost would not exceed one-eighth or one-tenth of that sum. Eventually the British Government had renounced the gift. Recently, as was well known, Dr. Erasmus Wilson, F.R.S., had munificently come forward and had offered to find the money if Mr. Dixon would undertake the engineering details involved in the transport of the obelisk to England. That offer had been accepted. The Kedhive, on being spoken to on the subject by Mr. Fowler, his Highness's chief engineer, and who was now in Egypt, said he should be pleased to see the obelisk removed to England if the Government would accept it on behalf of the nation. This the Government had consented to do, and it had again been presented to England through our Consul-General in Egypt. Nothing now remained, therefore, but to remove the obelisk to England. The stone was at present lying embedded in the sand on the shore of Canopus Bay, to the east of Alexandria. It was parallel to, and not far from the water-line, which washed the foot of a quay-wall backed up by the sand in which the obelisk was buried. The water was very shallow for a considerable distance out, and its bed was of rock covered with a fine sand, so that to dredge or excavate a channel for a vessel to come alongside the quay-wall and take the obelisk on board would involve an outlay of £50,000 or more. It would also be impossible to make a mole on which to convey the obelisk out to a vessel lying in deep water, simply because there was no material available, and even were there material, the length of mole required would necessitate an outlay of at least £30,000. Neither of these plans was available. What was proposed to be done was simply to excavate about the obelisk, and to build around it a huge iron cylinder or boiler, so to speak, ninety-five feet long and fifteen feet in diameter. In the first instance there would be constructed around the obelisk, ten feet apart, about seven diaphragms, discs, or collars, so to call them, circular on plan, and with square aperture in the center through which the obelisk passed, and would be held in position by wedges and other appliances so disposed and arranged as to prevent any excess of strain being brought to bear on the monolith under any circumstances, whether the cylinder containing it were held up in the center on the crest of a wave or at each end by two waves without any support in the center. To these diaphragms or collars would be built longitudinal girders and framing, which would in their turn carry concentric ribs of iron to receive the external skin of plate iron.

The obelisk will be disposed as nearly as possible in the center of this cylinder, which will have both its ends pinched up, so to speak, in wedge-form, to serve as bow and stern. On the side of the cylinder which is intended to remain uppermost manholes will be left for taking in ballast. The weight of the obelisk is about 183 tons. The cylinder, when completed, will be rolled out in the shallow water until it floats, being previously covered with a stout jacketing of timber-work, in order to prevent the possibility of its being damaged by any sharp pieces of rock which it may roll over. When the cylinder is in deep water it will be towed into the Khedive's dry dock at Alexandria, where the wooden jacketing will be stripped off; one of the wedge-shaped ends will be provided with a rudder, and the cylinder will be fitted with two bilge-keels and a small platform or deck, thus becoming a cylinder ship. It will be named the *Cleopatra*. Ballast will be taken on board to give the whole greater stability, which would have been secured, if the obelisk could have been taken on board an ordinary vessel, by placing the load nearer to the bottom than in the present case, where, in order to facilitate the rolling of the cylinder, the obelisk is to be placed in the center. All being ready and the weather favorable, the cylinder and its contents would be towed to England. Mr. Dixon went into details to show the stability of the vessel, as to which every care had been taken, seeing that not only was the safety of the obelisk involved, but the credit of English engineering was at stake. The plans of the vessel had been approved by Mr. Froude and other authorities on the subject of naval architecture. Having reached the Thames it would be towed to that part of the Embankment wall nearest to the site which might be selected, and at high tide would be floated on to a staging or gridiron of timber constructed to receive it. When the tide receded the cylinder would be left high and dry, and would then be raised by hydraulic power until the level of the embankment was reached. The keels, deck, and other excrescences having been removed, and the ballast taken out, the cylinder would be rolled across the Embankment to the site the obelisk was intended to occupy where the cylinder would be broken up and removed to the scrap-heap. Then came the question of raising the obelisk into an upright position on its pedestal. The Romans, and, later, the French, had pulled their obelisks up by ropes, but that plan necessitated a large number of capstans and other appliances. Mr. Dixon proposed to raise Cleopatra's needle in the following manner: Having brought the center of the obelisk over the exact site it was to stand upon, he should put round the central four feet or five feet an iron jacket, or, more properly speaking, a pair of iron stays capable of being so tightly laced or screwed up as to prevent the stone from slipping. On the centers of two of its sides this jacket would have projecting trunnions capable of bearing the whole weight of the obelisk.

The obelisk would then be gradually raised by hydraulic power, applied at each end alternately, and as it was raised a scaffold or staging of bulks of timber would be gradually built under it, the obelisks still lying in a horizontal position. When the timber staging had reached the required height, two iron girders would be placed parallel with the obelisk. Upon these girders would rest the trunnions before referred to, and the girders, resting upon the end portions of the timber-staging, would allow of the central portion of the staging being removed, so that the obelisk would swing nicely balanced on the trunnions, the bottom of the obelisk just clearing the stone on which it was to rest, and from that position could be easily lowered into its place by the lowering of the girders to a slight extent. One advantage of this plan was that on a bright moonlight night the stone could be experimentally lowered on to its pedestal to ascertain whether everything was right, and could then be pulled up again ready for the public ceremony. The lecture, which was illustrated by large plans on the walls, and by a model of the proposed cylinder-ship, attracted an unusually large audience, and an interesting discussion ensued.

PROFESSOR TAIT ON FORCE.

By ROBERT D. NAPIER.

From "Engineering."

The importance of having clear conceptions of the meaning of the terms used in reference to questions in dynamics, and Professor Tait's lecture on "Force" at the last meeting of the British Association, having deplorably intensified some of the most pernicious errors of ordinary writers on that science, which I undertake to prove he has done, is my excuse for asking you to insert this letter.

We are told in most treatises on dynamics that the same symbol represents both the acceleration produced by gravity and the force which produces the acceleration. I find in the preface to Young's Mathematics (1862) the following sentence, quoted from De Morgan, which should be printed in red letters in every treatise on dynamics: "Again, accelerating force which any one would suppose is the force which produces the acceleration, is no such thing; it is the effect produced, the very acceleration itself. I dwell upon this from a recollection of the confusion it created in my own mind when a student of the subject." This will show that I am not singular in protesting against this error, which I had all along supposed to arise from carelessness, and from a notion that it was somehow shorter and easier than to state the truth, that an effect can never be the cause of the effect produced. This mischief done by this gross carelessness, as I previously considered it to be, has been incalculable and lamentable, and the slovenly way of putting the case is inexcusable. However, we are now told by Professor Tait in his lecture, of which I had not till lately seen a full report, that in order to properly understand the subject, it is essential that we should clearly understand that "force *is* the rate of change of momentum," so that if a body is screwed up in a vice there is no force acting on either side of it; and yet we are told that we are to use the word force in exactly the same sense as Newton used it, and that it is obviously to be applied to any "strain, stress, pull, push," &c. We are also told that "any change in the rate of motion of a body is to be attributed to force," and that "momentum is mass × velocity." Now substituting in this sentence velocity for rate of motion, and the definitions of force and momentum for the words, we get the no doubt valuable, if obscure, information that *any change in the velocity of a body is caused by the product of the rate of change of its velocity × its mass.*

We are further informed that "force is a mere name," but that "the product of force into the displacement of its point of application has an objective existence." It is rather curious how passing a name over a distance has such surprisingly creative effects. Probably passing this created objective existence over a surface might create matter, and passing this matter through a volume might produce life. Huxley should look into this.

To illustrate his subject Professor Tait tells us that "a raised mass, in virtue of its elevation, possesses an amount of energy precisely equal to the work spent in raising it. This dormant or passive form is called potential energy." Is not the dormant energy somewhat contradictory in terms? Potential energy I can understand, but is it "stored up in the raised mass," as we are told in this lecture? An answer to this question may be found in another illustration given. "When we draw a bow we do work," and "the drawn bow has in it potential energy" . . . . "which can be expended on the arrow." If the work done in raising the weight is stored up in the weight, the work done in drawing a bow must surely be stored up in the arrow, which occupies an exactly similar position to that of the raised weight. If the work is stored up in the weight, how does it show itself? It must either be in the velocity of the body, or in its heat, or in its molecular condition; but none of these are altered any more than they are in the arrow when the bow is drawn back. It is the force of gravity that has been overcome through a definite distance—the body is totally unaffected; two forces were acting in opposite direction on it, but the body was as passive as the arrow. Force can no more exist without a resisting force than a rope can be stretched out horizontally unsupported with one end loose. After what has been said the following sentence hardly requires any comment. "We have just seen that when work is spent against molecular forces, as in drawing a bow or winding up a spring, it is stored up as potential energy," and "it is stored up in a similar form when done against gravity as in raising a weight." When the bow is drawn out or the spring wound up both have their condition altered, but in raising a weight its condition is not altered but only its position. When a man climbs a ladder, he finds he has lost energy and not gained it, and if a weight could do the same the result would be the same.

Its potential energy in reference to some position assumed to the stationary will vary as the square of its velocity in relation to that supposed fixed point, but the whole of the dynamical energy inherent in the body, is its inertia, or power of resistance to alteration of velocity.

TERRESTRIAL MAGNETISM AND THE MAGNETISM OF IRON VESSELS.

BY FAIRMAN ROGERS.

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II.

MAGNETISM OF IRON VESSELS.

20. IT has been supposed that the magnetic condition of certain rocks, well known as affecting the action of the needle when the compass is used on shore, would interfere with its action on the water, but although the compasses of a ship in a dock, surrounded by large masses of iron or moored in very close proximity to magnetic rocks, will be affected there is no reason to suppose that any rocks act upon the compass at the distance within which vessels ordinarily approach the shore.

A compass placed upon a ship built wholly of wood, would be subject only to the variations which we have considered, and they are now determined with sufficient accuracy to prevent any danger occurring from their interference; but in a vessel, in the construction of which iron is used to a greater or less degree, or in a steam vessel, there are disturbances of magnetic condition which are of the utmost importance.

21. In the first place, soft iron without any magnetism of its own affects the compass (19), since under certain conditions it becomes temporarily a magnet; while iron which has acquired any degree of magnetism either by position or by manipulation acts upon the needle in a still more powerful manner. If we balance a long needle in such a way that it may move freely in both a horizontal and a vertical plane, and then magnetize it, it will turn into the vertical plane of the magnetic meridian, and will dip in that plane according to the magnetic latitude of the place of experiment, (16).

If we suspend a bar of soft iron in the same position it will immediately acquire magnetic force, which it will lose again in proportion as it is moved out of this position, (19). In consequence of this, iron in a vertical position frequently affects the compass to a great extent. In the case of U. S. Sloop of War, Ticonderoga, examined in 1863, the standing mizen rigging which was of iron wire, acted so powerfully and in such a varying manner upon the steering compass, which was in a line joining the mizen chains, that it was found necessary to remove it and substitute hemp rigging before the compass could be corrected in any satisfactory manner.

In fact all the deck beams and pieces of iron in a vessel become magnetic to a greater or less extent, and as they change a portion of their magnetism with changes of position, they act differently upon the compass as the ship heads in different directions; and as they slowly lose or gain, relatively or absolutely, their action changes also as time elapses.

22. As the effect on the compass in such cases is the resultant of the action of a large number of pieces of metal in different positions, the determination of this effect must always be a matter of experiment with each particular vessel and for each position on it; but the consideration of the action of certain masses in a few positions will lead to results that may enable the officer to select the position in the ship which will be most free from disturbances, and frequently to make such dispositions as may neutralize the peculiarily bad effects of certain arrangements.

It will also enable us to correct the compass empirically, by introducing disturbing causes which will nearly balance those arising from the material of the vessel.

23. We must be careful to distinguish clearly between variation and deviation.

The *variation* is the amount by which the compass points E or W of the true North, by reason of the want of coincidence of the magnetic pole with the pole of the earth (6) the *deviation* is the amount by which the compass deviates from the *magnetic* North and depends upon the ship's action and position.

24. In one sense we may consider an iron vessel as a magnet which acts upon

the needle as the earth does, and the needle will in that case be acted upon by the combined forces of the earth and the ship, and will assume a position depending upon the mechanical resultant of those forces.

Thus if the ship is so magnetized that the north end of the needle is attracted toward the bow, *and* the ship is heading to the magnetic North*, the action of the ship and the earth being in the same direction, the needle will not be disturbed. If, now, the ship alters her course, so as to head East, the needle will be drawn by the earth's force toward the North, and, by the ship's force to the East, and must, therefore, assume a position between the North and East, depending upon the relative amount of the two forces.

The amount by which the needle is drawn from the magnetic North is called the deviation, and in the case which we have supposed, this deviation will change with azimuth of the ship's head, being zero when the head is to the North, and attaining a maximum when the head is toward the East or West.

It is this deviation that we wish to study so as to be able to predict it, to allow for it, or to correct the compasses so as to eliminate it. The action of the ship upon the compass is not, however, so simple as above supposed.

The force of the ship is never exactly to the head, but in a direction making some angle with the axial line of the ship, and therefore, for convenience, we divide this force, as we do that of the earth, into two components at right angles to each other, viz., the ship's *force to head*, and the ship's *force to starboard*, as *ab* and *ac*, Fig. 1, *ad* the resultant representing in direction and amount the ship's force.

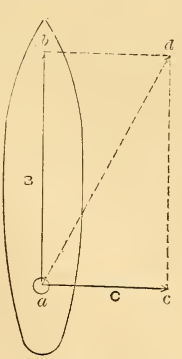


Fig. 1

We may also separate the *vertical* component of the ship's force but we shall not consider that at present.

26. To determine the amount and direction of the ship's horizontal force, any compass may be used, the needle of which traverses freely, but the more delicate the instrument the more satisfactory will be the results.

Place the compass in a position on shore free from any local attraction, and by means of a small magnet or a piece of iron deflect the needle 90° from the north point, permit it to vibrate and count the number of vibrations in a minute, repeating the observation several times to ensure accuracy. If the number of vibrations of the different sets do not agree within a quarter of a vibration either the instrument or the observer is at fault.

This number of vibrations in a minute gives a measure of the earth's horizontal force at the place. Then take the *same* compass on board the ship and count the number of vibrations in a minute made there. The ship's force with her head in the particular position at the time of the observation and at the place occupied by the compass will be to the earth's force as the square of the number of vibrations on board is to the square of the number on shore. A single observation on board will give a result, but it is much better to make a number with the ship heading in different directions, for the magnetism of the soft iron changes, as we have seen with changes of direction.

To show how the amount and direction of the ship's force may be plotted and determined, we give an example at length, when the ship's force is greater than that of the earth, and the condition therefore somewhat exaggerated.

In this case the ship is represented by a rectangle of cast iron, which has become permanently magnetic, the compass being placed in the middle of it and one end of the rectangle marked as the bow.

No. of vibrations on shore, that is not surrounded by the iron representing the ship, 9.5 in a minute. Bow to the North, No. of vibrations, 20.5; Needle pointing

* It will be understood that in this treatise, North always means Magnetic North, unless otherwise stated.

6° W of N. Bow to the East, No. of vibrations, 18.75; Needle pt. 72° E of N. Bow to the South, No. of vibrations, 16.5; Needle pt. 7° E of S. Bow to the West, No. of vibrations, 18.40; Needle pt. 84° W of N. Now, as in these positions on board ship the needle is under the influence of the ship and the earth both, these directions and vibrations are due to the combined influence of earth and ship, and represent in direction and amount the resultant of the forces of earth and ship, and the forces are to each other as the squares of the number of vibrations, according to the law of the pendulum.

We have, therefore,

On shore,	$9.5^2 = 90.25$		
Head N,	$20.5^2 = 420.25$	Amount of resultant force	6° W of N
Head E,	$18.75^2 = 351.00$		72° E of N
Head S,	$16.5^2 = 272.25$		7° E of S
Head W,	$18.40^2 = 338.56$		84° W of N
			Direction of resultant force.

We may now plot this so as to obtain the amount and direction (with reference to the ship) of the ship's force. In Fig. 2 let C be the position of the compass, the north being to the top of the page, CN′=90.25 representing in direction and amount the force of the earth, and C N =420.25 N 6° W, representing in direction and amount the resultant of earth and ship, the force exerted by the ship will, therefore, be represented by CO=330, and 8° to Port of center line of ship.

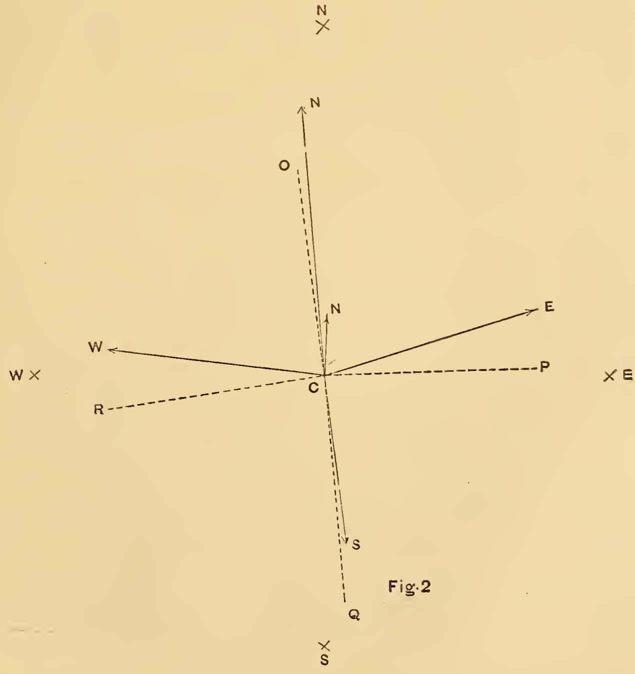
So with head E, CE=351, N 72° E represents resultant of earth and ship, and CP the force of ship 335, 2° to Port of center line.

Again, with head S, C.S=272.5 S 7° E. and CO=368, 5° to Port of center line.

With head W, CW=338.56 N 84° W and CR=440, 9° to Port of center line.

Therefore, ship's force is $\frac{330+335+340}{3}$ =335 in amount as compared with earth's force, 90.25 or 3.71 earth's force being 1.00 and $\frac{8+9+2+5}{4}=6°$ to Port of center line in direction, the line passing through the position of the compass.

In taking the average of the amounts, the value to the S 368 is omitted, because the action of the earth and that of the ship being directly opposed, the needle is sluggish and its number of vibrations cannot be depended upon. This is an extreme case, since usually the ship's force is less than that of the earth, but it is selected because it shows the method better in plotting.



Fig·2

Of course, these values can be calculated by the ordinary means if greater accuracy is desired. It is obvious, also, that if only one or two observations can be made they are better with the head E or W than N or S.

It must be remembered that the direction and amount of the ship's force varies with her position within certain limits, and that one line can, therefore, only represent the mean force and direction.

Part of her force comes from her soft iron, and in this paragraph (26) we have considered that only her permanent magnetism is affecting the needle.

In Fig. 2, the line CE is the resultant (or diagonal of the parallelogram) of CN′ and CP; knowing CN′ and CE we construct the parallelogram CN′ EP and thus find CP which is required, and the same with CQ CR and CO.

Although the ship acts upon the compass as a whole, like a magnet; still it is not like a simple magnet but one which changes its magnetism in different positions, and in fact its action is made up of the separate action of different parts.

27. The investigations of Poisson and Airy, show that part of the action of the ship is due to the permanent magnetism of the hard iron, and a part to the induced magnetism of the soft iron, (18) and the action upon the needle or the deviation can be expressed by a mathematical formula. The formula given by Poisson is more complete in some respects than that given by Airy, but the latter is simpler and is as follows:

$$S = A + B \sin. z' + C \cos. z' + D \sin. 2z' + E \cos. 2z'$$

in which S is the deviation to be determined.

Z′ is the azimuth of the ship's head by the disturbed compass.

And A, B, C, D, E are coefficients whose values are determined by experiment.

Table I gives an analysis of these coefficients and should be carefully studied.

28. A is constant for the same ship and compass, and is real or apparent as shown in the table.

It is generally very small except in the case where the compass is not in the middle line of the ship. All these coefficients are positive (+) when they act towards the head or the starboard side, negative (−) when they act to the stern or to port.

29. B and C together represent a force which acts as represented in Fig. 1, and which has its zero when the ship's head is in a certain direction, (usually towards the North), and its maximum when the head is at right angles to that direction, from which peculiarity it is called the semicircular part of the deviation.

It is caused: I, by the permanent magnetism of the hard iron, and as that is constant it varies inversely as the earth's horizontal force; II, by the induced vertical part of the earth's force on soft iron, and therefore changes with magnetic latitude as the dip changes.

As this force rarely acts in the direction of the ship's length we divide it into two, B, acting fore and aft, and C acting athwart ships. (5 of the table).

30. D and E represent a force which is due to the horizontal induction of soft iron, and which is called the quadrantal part of the deviation for the following reason.

If a bar of soft iron is held in the direction of the dip it becomes a magnet, the upper end of which, in North latitude, attracts the N end of the magnet, (21) if it is moved into a horizontal position, but still pointing North and South it is still magnetic, under the influence of the horizontal component of the earth's force though in a smaller degree. If it is now moved horizontally into an East and West position, its magnetism still further diminishes and when it reaches the East and West position its magnetism disappears altogether.

If, therefore, a compass is acted upon by this bar, when the bar is North or South of the needle, it attracts it strongly, but as the needle is already pointing North, its directive force (7) is increased, but its direction is not disturbed; if the bar is carried around radially, say to the East, the needle is drawn toward it and so has an Easterly deviation.

But the bar as it approaches the E and W position, loses its magnetism; and when E and W has none, and therefore does not attract the needle, and produces no deviation; consequently, the deviation will be zero when the bar is N and S and N of the compass, zero when the bar is

Deviation of the Compass in Iron Ships.

$$\delta = \mathbf{A} + \mathbf{B}\ sin.\ Z' + \mathbf{C}\ cos.\ Z' + \mathbf{D}\ sin.\ 2\,Z' + \mathbf{E}\ cos.\ 2\,Z'.$$

δ = *deviation.* Z' = *azimuth of ship's head by disturbed compass.*

Constant: A
- Real: *from induction of* horizontal *force on* soft *iron unsymmetrically distributed.*
- Apparent: *from* index *or obs. error.*
  - + *When Easterly deviation is in excess.*
  - — *When Westerly deviation is in excess.*

A *is common in character and value in all classes of vessels. It may occur in heeling, from the propeller shaft being thrown to one side, but it is very small.*

May also occur from horizonal spindle of steering apparatus.

Semi-circular or Polar magnet. *from*
- 1. *Permanent magnetism of* hard *iron, varying inversely as the* Horizontal force *at the place.*
- 2. *That induced by the* vertical *part of the earth's force on* soft *iron, varying as the* tan*gent of the dip.*

B *is that part of this combined attraction acting in* a fore and aft *direction (the nat. sin. of B is* ship's force to head).
- + *if* forward *of the compass.*
- — *if aft of the compass.*

C *is that part of this combined attraction acting* athwart ship *(the nat. sin. of C is* ship's force to starboard).
- + *if to star*board.
- — *if to* port.

The resultant of B *and* C *is the* ship's force, *and is in its direction* $\left[\tan.^{-1}\frac{C}{B}\right]$ *and amount* $\left[\sqrt{B^2+C^2}\right]$ *equivalent of the* "true starboard angle."

In the wood-built *vessel (in Great Britain)* B *is* + *when the engines are for*ward *of the compass, and* C *is always small in value. In the* iron built *vessel* B *is irrespective of machinery*
- + *When the ship was built* head South.
- — *When the ship was built* head North.

and nearly vanishes when head was E. or W.
- 1. *In an* iron *vessel built in England head* South, *the* N. *end of the needle is drawn to the* bow *or* B *is* +. *The machinery has the* same *effect and must be* added.
- 2. *Ditto, head to the* North, *the* N. *end is drawn to the* stern, *or* B *is* —. *The machinery has the* contrary *effect, and must be subtracted.*

and C *may be large and either* + *or* —.

The semi-circular deviation is sensibly diminished by raising the compass to a short distance above the deck beams.

As it depends upon the dip it is **O** *at the magnetic* equator, *and a* maximum *at the magnetic* poles.

Quadrantal *sometimes called* permanent *coefficients, because unchanging in all magnetic latitudes.* — *due to* horizon*tal induction of* soft *iron in ships.*

- **D** *has four maxima at* intercardinal *points.* — *Symmetrically distributed.*
  - + *When from masses acting* in fore and aft *direction.*
  - — *When from masses acting* in transverse *direction.*
- **E** *has four maxima at* cardinal *points, and is generally so small that it may be neglected.* — *Unsymmetrically distributed.*

D *ranges in iron vessels from* $+1\frac{1}{2}°$ *to* 7° *(even 11°), and in* wood, screw *vessels, seldom exceeds* +1° *(sometimes* —*), and in* wood, side-wheel *vessels* $+1\frac{1}{2}°$.
E *is common in character and value in all classes of vessels.*

D *has the following characteristics:* 1. *Invariably* +. 2. *Its amount does not depend upon the size of the vessel* or direction *when building or on iron* beams. 3. *It gradually* decreases *with time.* 4. *It is unchanging in all magnetic latitudes.* 5. *Its value is from* 2° *to* 4°.

The quadrantal deviation is diminished by raising the compass to the mast head, but not by changing within two to six feet from the deck.

E and W and E of the compass and will have a maximum somewhere between N and E.

It will be the same in each quadrant except that in the second quadrant E to S the S end of the needle will be attracted by the N end of the bar, thus giving a W deviation. E in the S to W quadrant and W again in the W to N quadrant. See Fig. 3.

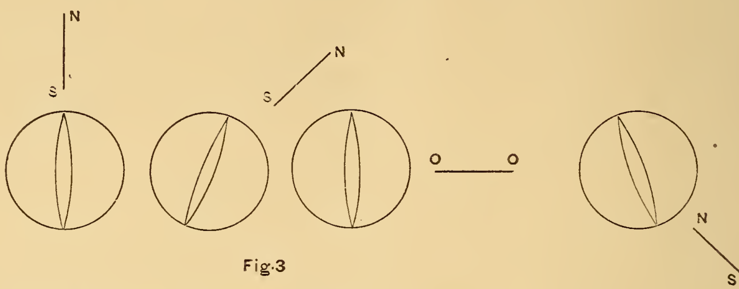


Fig. 3

The top of the page represents the North.

This quadrantal deviation is divided into two parts, D, which is the more important, and which has its maxima at or near the intercardinal points NE, SE, SW, NW and E which has its maxima at the cardinal points N, S, E, W, and which is generally so small that it may be neglected. It arises from soft iron unsymmetrically distributed.

31. Of the five coefficients, A and E are small, and B, C, and D are the important ones to consider, and those we shall therefore discuss at greater length.

A portion of the action which introduces the coefficients B and C is, as already noticed, due to the permanent magnetism of the hard iron composing the ship.

A piece of hard iron or steel may be made a permanent magnet by touch with another magnet, by subjection to the action of a current of artificial galvanism or by being placed in such a position that the currents of the earth will magnetize it.

The last is the only method by which a vessel will be magnetized, and as the currents of the earth have a definite relation in their direction to the earth itself, it is evident that the magnetism of an iron vessel will vary with the position which the ship has during its building, or in the case of an iron clad, during its plating. Late investigations* have indicated that the North end of the needle is attracted toward that part of the vessel which was nearly South in building.

That this magnetism is more constant in vessels built North and South than in those built East and West.

That the diminution of the directive force is greater if the ship has been built E and W, than if built N and S.

That the deviations in a ship built E and W are less symmetrical, regular and permanent than those on a ship built N and S. From which it is evident that it is better to build ships N and S, than E and W. When the compass is to be placed in the after part of the ship, as is the case with most of our war vessels, it is best to build the vessel head to the South, because if the ship is built head North the upper part of the stern, and the lower part of the bow, will be strongly magnetized, and the lower part of the stern, and the upper part of the bow weakly, so that a compass placed near the stern will have a large semicircular deviation.

If the compass is amid-ships the direction in building is not important, and if the compass is forward as in some merchant propellers, the head should be North in building.

32. The amount of magnetism upon which B and C depend is affected by the treatment which the vessel receives during building, and after being launched and in the early part of her service.

If in a vessel to be plated, built with the head North, a certain amount of magnetism is introduced by her position, another amount having an opposite effect upon B and C may be introduced by plating the vessel with her head South, and in this way the semicircular deviation of an after compass (31) may be much diminished, annulled or reversed

* Evans and Smith, Phil., Trans. Pt. I, 1865.

by this operation, a fact of great importance, since although the position for building cannot often be chosen—such a position for plating as will modify this element of the deviation, can almost always be selected by choosing one or the other side, or the end of a wharf, and mooring the vessel bow in or bow out.

No case has been reported, within the knowledge of the writer, in which the complete experiment has been made, but the observations on the Warrior, Black Prince, Defence, Resistance and Valiant (Evans and Smith, Phil., Trans. Pt. I 1865) where the directions before and after plating were different, have given just the results which might have been anticipated.

Again the permanent or subpermanent magnetism is affected by the jars or blows to which the iron may be subjected; thus if (19) a bar of iron held in the direction of the dip, be struck with a hammer it will become more highly magnetized than if it is held quietly; and shaking or pounding when in an E and W position will cause it to give up some of its charge.

For the first few months after launching, during which time the vessel is exposed to the hammering of the workmen in completing the work, to the vibrations of the machinery, and to the shocks of the waves, the values of B and C change, generally diminishing until they attain a permanent value in about one year.

Swinging at anchor through all azimuths, or merely lying quietly in a direction differing considerably from that of building, will also cause some changes.

It is evident that this magnetism is not exactly permanent as that of a steel magnet is, and it is therefore sometimes called subpermanent.

33. It follows from these considerations that we may by judicious management, so modify the action of the hard iron, as in many cases to reduce the value of B and C to within small limits as far as they depend upon the permanent magnetism, and that this magnetism becomes settled or *shaken down* at the expiration of twelve months.

34. Now the intensity of the earth's attraction of the needle to the North depends upon the magnetic latitude (16), and the ship's action being permanent in amount, the total directive force upon the needle will vary with the latitude, the effect of the ships becoming apparently greater as that of the earth becomes less, and B and C will therefore increase inversely as the horizontal force at the place, and will increase as the ship goes from the equator towards the poles.

35. There is another part of B and C (No 2 Table 1), that induced by the vertical part of the earth's force on soft iron of the vessel, which varies as the tangent of the dip; that being the representative of the vertical part.

This can be separated from the first by treating observations made in different latitudes, or when the vessel is on an even keel and when she is heeled as in the last case, the transverse iron, such as beams, posts, and the ship's sides, change their induced or temporary magnetism as they change their inclination.

The difficulties of heeling a vessel are however very considerable, and up to this time observations have not been made with sufficient differences of latitude to give very good results, so that 1 and 2 are not well separated.

The change of induced magnetism in the soft iron of the vessel is of great practical importance, however, in another respect, for when an iron sailing vessel or a steamer under sail, is careened by the wind, the deviation is sometimes much affected temporarily, and an error sometimes quite large, introduced, called the heeling error.

36. So far we have only considered the deviations while the ship is on an even keel, but they may vary when she heels to port or starboard, and as in some localities, a vessel may sail for days with the wind on the beam, this unexpected addition to the deviation may carry her out of the way.

The heeling error is produced by the action of the permanent magnetism, and by that of the induced magnetism of the transverse soft iron.

The direction of the ship's force is not necessarily horizontal, (25), in fact it is nearly always inclined more or less in the vertical plane. If it is of such a character as to draw the N end of the needle downwards, in the position of compass, it is said to act downwards, and it is evident that in this case, when the ship heels, the N end of the needle will be drawn to the weather side.

Again, the transverse iron such as deck beams, become magnetic as they incline, and their upper or weather ends attract the north point of the needle, thus further increasing the heeling error. If, however, the ship's force at the compass acts upwards, the needle is attracted by that to the lee side, and by the induction of the deck beams to the weather side, and thus the heeling error is reduced or practically destroyed. This is one strong argument in favor of building vessels head South in North latitudes, since such ships usually have an upward force in the after part where the steering compass is placed.

The effect of the induction will be at the magnetic equator, and will be reversed, as the upper end acquires magnetism south of the equator. Therefore, as far as this error is concerned, ships built to run in South magnetic latitudes, should be built head North.

This heeling error may be compensated on the same principle as the other deviation (46), by placing a vertical magnet in such a position, vertically under the compass, that it will produce no deviation when the ship is on an even keel and just enough of an opposite kind as the ship heels to counteract that produced by the ship itself. This will not be entirely satisfactory, since the error from induction in the soft iron will change with the latitude but it will reduce the error considerably.

Owing to the difficulty of heeling a vessel, there are not so many observations on this point as is desirable, and they should therefore be made whenever opportunity occurs. In all cases the angle of heel should be carefully determined and recorded with the results of the observations. In some vessels the error is very large, as in the City of Baltimore, 2° of deviation for each degree of heel. It is evident that as the heeling error due to the permanent magnetism is constant and that from induced magnetism varies with the magnetic latitude, observations of heeling error in the same ship and compass in different latitudes will enable us to determine the relative effects of the two, and such observations are very desirable, (35).

Vertical iron also produces a heeling error and in English iron merchant-men, where the steering compass is usually well aft., it has been found necessary to put up a vertical iron post forward of and below the compass to compensate for the effect of the stern post. Tunnels, bulkheads, etc., frequently cause a heeling error.

The error is greatest in N and S courses, and least in E and W.

In compasses compensated by Airy's method with the magnets below the compass, the heeling error is much reduced.

Elaborate records of experiments in heeling vessels will be found in Appendix to Third report of Liverpool Compass Committee, 1862.

37. In considering the formula given in Section 27, it is evident that if we can get a sufficient number of equations with different values of δ and Z' depending upon each other, we may determine the value of A, B, C, D and E.

This can be done in the following way: The ship being at anchor in a place where there is no current or moored in a basin where she is not in the immediate neighborhhood of large masses of iron or magnetic rocks, some distant object or objects must be selected, the correct bearing of which from the ship must be determined from the chart, or by careful observations *on shore* with an azimuth compass. The object must be distant, so that its bearing will not be sensibly changed by a small change in position of the vessel. (See Sec. 26 for other methods of determining deviation.)

The standard compass must then be set up on board at a point in the *midship* line of the vessel which has been selected upon general considerations hereafter to be noticed (49), or after several observations of the kind now to be described.

In most vessels a position between the main and mizen mast will be found to be the best.

The vessel's head being brought to any cardinal point, say to the North, by the standard compass, the bearing of the distant object by this compass must be read off and entered opposite the heading of the vessel as in column 2 of the table.

The difference between the true magnetic bearing of the distant object and its bearing by the compass will be the deviation, (δ) for that azimuth of the ship's head (Z') and must be entered in

3rd column of the table on the first line. The ship's head must then be swung towards the East, either by warps or with the assistance of a steam tug or boats until her head is N *b* E by the standard compass, the bearing of the distant point is again noted, entered opposite N *b* E, and the deviation on that course deduced. The same observations must be made all around the compass, except that in entering them, it is convenient, as will be seen, to make a fourth column, and begin it with the readings at South as on page 554.

In practice it will not generally be found necessary to *stop* the ship at each of these points, as the observation can be made at the moment her head is in the right direction, provided she is not swung too fast.

It is also quite possible to make the observations in a tide-way, which is not too strong, by taking advantage of the ship's swinging with the tide, although difficulty will sometimes be experienced in making her go all around at the next turn, instead of back through the side of the circle in which the first half of the observations were made.

For instance, if with the first tide the ship swings from N to South by the East, in many tide-ways she will, without some extraneous aid applied at the right time, be apt to swing back to N by the East, and not by the West.

A method (Napier's diagram) is given, (42) by which observations made on any azimuths, not necessarily N, N *b* E, &c. can be used.

This table of deviations may be used in practice to steer by, since it shows the error of the compass on each course, thus in the case of the Calypso when the ship heads N by standard compass the needle points 6° 14′ to the W of Mag. N and the ship would be sailing more than half a point to the W of N so that a corresponding correction must be applied to enable a true N course to be steered.

38. To proceed to the computation of the coefficients A, B, C, D, and E.

It is shown in the English Admiralty Compass Manual (Evans and Smith) by a mathematical demonstration too long to be introduced here, that the values of these coefficients may be deduced from the thirty two equations, giving the value of S by performing the operations indicated in the form given on page 554.

Prepare a form according to this example, the permanent part of which is indicated by the Roman letters and figures, and the quantities to be entered by the Italics.

Enter in the second and fourth columns the deviations as observed on each point, giving Westerly deviations this sign— and Easterly ones the sign +.

Form column V by entering the algebraic sums of figures in columns II and IV, having reference to the signs, and dividing by two; and form column VI by adding figures in cols. II and IV the signs of quantities in col. IV being changed, and dividing by two.

It will be seen upon reflection, and especially if the figures in these columns are plotted (see page 555) so as to aid the mind in comprehending these, that the figures in the sixth column are the means of the deviations in the semicircles from N to S, by the East, and from N to S, by the West, and represent therefore the mean semicircular deviations, and that those in column five represent the excess of the greater quantities over the mean, and represent therefore the quantities which affect the deviations, apart from the semicircular deviations, namely, the quadrantal deviations. On page 555 these are plotted, lines II and IV representing columns II and IV, and line VI the mean semicircular deviation.

Line V crosses the center line twice between N and S, and represents the quadrantal part of the deviation, line VI crosses once and represents the semicircular part.

If there were no quadrantal deviation lines II and IV would be nearly regular and symmetrical curves, equal on both sides of the axis, but the effect of the quadrantal deviation is to add to the semicircular deviation on the side towards which it acts, and to diminish it on the other side. For example, the mean deviation, Fig. 4, at N (or S) is $-6°57'$ (long dotted line VI) but II is drawn towards the plus side, to a reading of $-6°45'$ and IV is pushed to the same side to a reading of $+7°09'$. The difference between these readings, $+0°24'$ represents twice the action of the quadrantal deviation and $\frac{+0°24'}{2} = +0°\,12'$ repre-

Record of Deviations and Computation of Coefficents.

U. S. Steamer "Calypso," Acting Master, F. D. Stuart, August 17, 1865.

B and C.

I. Ship's head by disturbed compass.	II. Observed deviation of compass.	III. Ship's head by disturbed compass.	IV. Observ'd deviation of compass	V. Half sums of quantities in cols. II, IV. Unchanging part of deviation.	VI. Half sums of quantities in II, IV, signs of IV chang'd. Semicircular deviation.	Computation of B. VII. Multipliers.	VIII. Products of col. VI by multipliers.	Computaion of C. IX. Multipliers.	X. Products of col. VI by multipliers.
N	— 6° 45′	S	+ 7° 09′	+ 0° 12′	— 6° 57′	0	0° 00′	1	— 6° 57′
N by E	— 6 00	S by W	+ 8 00	+ 1 00	— 7 00	S_1	— 1 22	S_7	— 6 52
N N E	— 4 21	S S W	+ 9 13	+ 2 26	— 6 47	S_2	— 2 35	S_6	— 6 16
N E by N	— 3 10	S W by S	+ 8 33	+ 2 41	— 5 51	S_3	— 3 14	S_5	— 4 51
N E	— 0 55	S W	+ 7 36	+ 3 20	— 4 15	S_4	— 3 00	S_4	— 3 00
N E by E	+ 0 51	S W by W	+ 5 30	+ 3 10	— 2 20	S_5	— 1 56	S_3	— 1 18
E N E	+ 1 20	W S W	+ 2 47	+ 2 03	— 0 43	S_6	— 0 40	S_2	— 0 16
E by N	+ 1 30	W by S	— 0 41	+ 0 25	+ 1 05	S_7	+ 1 04	S_1	+ 0 13
E	+ 1 50	W	— 1 28	+ 0 11	+ 1 39	1	+ 1 39	0	0 00
E by S	+ 2 00	W by N	— 3 09	— 0 34	+ 2 34	S_7	+ 2 31	$-S_1$	— 0 30
E S E	+ 2 20	W N W	— 6 11	— 1 55	+ 4 15	S_6	+ 3 56	$-S_2$	— 1 38
S E by E	+ 2 50	N W by W	— 8 40	— 2 55	+ 5 45	S_5	+ 4 47	$-S_3$	— 3 12
S E	+ 3 55	N W	— 9 10	— 2 37	+ 6 32	S_4	+ 4 37	$-S_4$	— 4 37
S E by S	+ 4 00	N W by W	—10 00	— 3 00	+ 7 00	S_3	+ 3 53	$-S_5$	— 5 49
S S E	+ 4 50	N N W	— 9 06	— 2 08	+ 6 58	S_2	+ 2 40	$-S_6$	— 6 26
S by E	+ 5 22	N by W	— 8 05	— 1 21	+ 6 43	S_1	+ 1 19	$-S_7$	— 6 35
Easterly deviations +					Sum of + terms =		+26 26		+ 0 13
Westerly " —					Sum of — terms =		—12 47		— 58 17
					divided by 8)		+13 49		8) — 58 04
					B =		1° 43′		C = — 7° 16′

A, D and E.

XI. Upper half of col. V.	XII. Lower half of col. V.	XIII. Half sum of quantities in cols. XI, XII. Const'nt part of deviation.	XIV. Half sum of quantities in cols. XI, XII with signs of XII changed. Quadrantal deviation.	Computation of D. XV. Multipliers.	XVI. Products of col. XIV by multipliers.	Computation of E. XVII. Multipliers.	XVIII. Products of col. XIV by multipliers.
+ 0° 12′	+ 0° 11′	+ 0° 12′	0° 00′	0	0° 00′	1	0° 00′
+ 1 00	— 0 34	+ 0 13	+ 0 47	S_2	+ 0 18	S_6	+ 0 43
+ 2 26	— 1 55	+ 0 15	+ 2 10	S_4	+ 1 32	S_4	+ 1 32
+ 2 41	— 2 55	— 0 07	+ 2 48	S_6	+ 2 35	S_2	+ 1 04
+ 3 20	— 2 37	+ 0 21	+ 2 58	1	+ 2 58	0	0 00
+ 3 10	— 3 00	+ 0 05	+ 3 05	S_6	+ 2 51	$—S_2$	— 1 11
+ 2 03	— 2 08	— 0 02	+ 2 05	S_4	+ 1 28	$—S_4$	— 1 28
+ 0 25	— 1 21	— 0 28	+ 0 53	S_2	+ 0 20	$—S_6$	— 0 49
Sum of + terms =		+ 1 06	Sum of + terms =		+ 12 02		+ 3 19
" — " =		— 0 37	" — " =		— 0 00		— 3 28
divided by 8)		+ 0 29	divided by 4)		+ 12 02		4) — 09
A =		+ 0° 03.′6	D =		+ 3° 00′		E = — 0 02′

sents the quadrantal deviation at N (or S).

The reader can make this still clearer by plotting from a center line, any regular semicircular deviation, and any regular quadrantal deviation, and then plotting the resulting deviation course (Fig. 5), an operation the converse of the above.

In Fig. 4 the line VI is the mean of the two lines II and IV, IV having been turned over on to the same side of the axis as II, or having its *signs changed* (Col. VI).

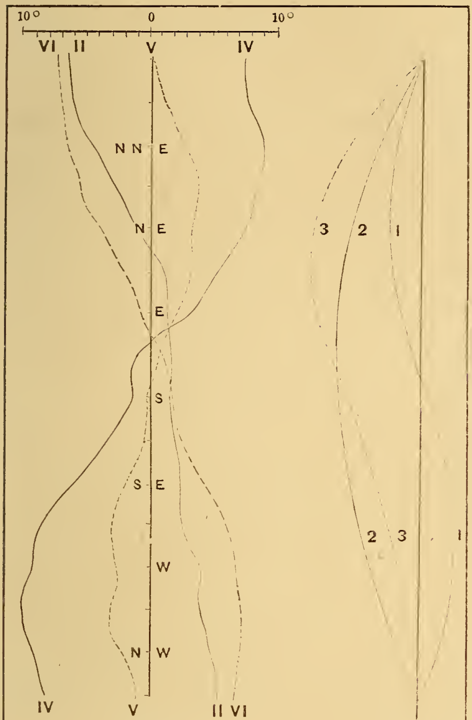


Fig. 4 Fig. 5

38. Having thus separated the semicircular and quadrantal deviations, we proceed to compute B by multiplying each number representing the deviation in Col. VI by the natural sine of the rumb of the course counting from the North, that is by O, S_1, S_2, &c., which are taken from the following table :

S_1=nat. sin.	11°	15′	=.19509	1	point.
S_2= "	" 22	30	=.38268	2	points.
S_3= "	" 33	45	=.55557	3	"
S_4= "	" 45	00	=.70710	4	"
S_5= "	" 56	15	=.83147	5	"
S_6= "	" 67	30	=.92388	6	"
S_7= "	" 78	45	=.98078	7	"

In the English Admiralty Compass Manual, a table is given of the products of S_1, S_2, &c., with arcs up to 35°, which facilitates the operations very much.

These values are entered in column VIII.

The sums of the + terms, and of the — terms in this column are then taken and their difference with its proper sign + or —, divided by 8 gives the value of B in arc, as in the example B= +1°43′. We then form column X by multiplying the same quantities by the nat. sines of the rumbs, counting from E or W, to get C, which acts at right angles to B, the quantities S_1, S_2, &c., being entered in the inverse order.

The algebraic sum of the quantities in X divided by 8 gives the value of C, in example, C= —7° 15′.

Then to obtain the values of D and E, the quadrantal coefficients we take column V and entering the quantities in the upper half in column XI, and those in the lower half in column XII, since we wish to get the mean of the quadrantal deviation, we perform in columns XIII and XIV, the same operations as in columns V and VI, eliminating the constant or index error A, and getting quantities in column XIV to be multiplied by S_2, S_4, S_6, etc., computing D and E as shown in columns XVI and XVIII. In the example A= +0° 03′6 D= +3°00′E= —0°02′.

In case the observations are made on 16, instead of 32 points, that is at N., N.N.E., N.E. etc., the columns will be only half as long, and the divisions for B. C. and A will be 4, and for D and E, 2, instead of 8 and 4, but the resulting values of the coefficients will not be so exact. Observations on 8 points will give less reliable values and observations on the four cardinal points will not give a value of D nor those on the quadrantal points, a value of E.

As D is more important than E, if observations on four points only should be possible in any case, they should be made on the quadrantal points.

It is obvious that having the values of the coefficients we may compute the deviations on any course to half or quarter points by substituting in each equation the azimuth of the course *f Z′*.

40. These coefficients are, strictly speaking, only approximately correct, the more accurate values being expressed by $\mathfrak{A}$,$\mathfrak{B}$,$\mathfrak{C}$,$\mathfrak{D}$,$\mathfrak{E}$, which are attained as follows :

$$\mathfrak{A}=\sin. A$$

$$\mathfrak{B}=\sin. B[1+\tfrac{1}{2}\sin. D+\tfrac{1}{12}\text{ver. sin.}B-\tfrac{1}{4}\text{ver. sin. }C]+\tfrac{1}{2}\sin. C\sin E$$

$$\mathfrak{C}=\sin. C[1-\tfrac{1}{2}\sin. D+\tfrac{1}{12}\text{ver.sin. }C-\tfrac{1}{4}\text{ver. sin. }B]+\tfrac{1}{2}\sin.B\sin. E$$

$$\mathfrak{D}=\sin. D[1+\tfrac{1}{3}\text{ver.sin.}D]$$

$$\mathfrak{E}=\sin.E$$

For all ordinary purposes, however, the values represented by A, B, C, D, and E are sufficiently close.

41. The deviations may be observed by other methods than that of swinging the ship on known bearings. If in dock, or in a confined harbor, a compass carried around ship on shore, by an observer who keeps always in a line with the masts will, at each moment, give the true magnetic bearing of the head of the ship; and she can be stopped on any desired point, or observations of her compass be made as she reaches each point in succession, by means of signals agreed upon by those on shore and on board.

Or the shore compass being kept in one spot, reciprocal bearings of the shore compass, and the ship's compass, can be made in each position of the ship which will agree if there is no deviation, and will differ by the amount of deviation on each course. In using this method, it has been suggested that the readings in each case should be chalked upon a blackboard to be seen by the opposite observers, in order that they may be certain that the readings and records are correct, before making each new observation.

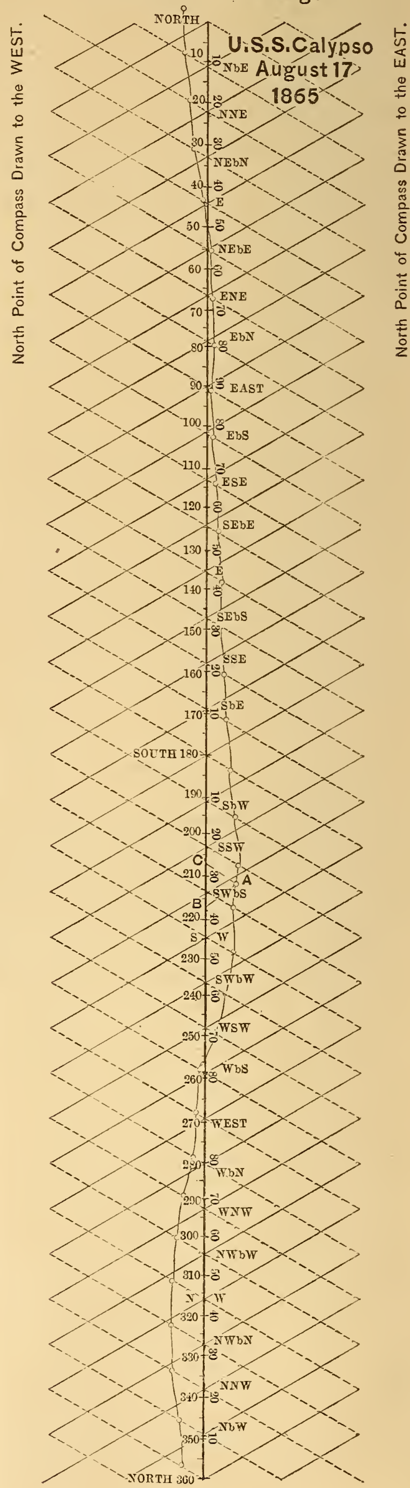
In the case where the standard compass, having been placed in a carefully selected position (49), is perfectly corrected, it will be used as the ship swings to determine the deviations of the other compasses in their different positions on board.

42. The deviations in different courses may be plotted by laying down a straight line to represent no deviation and dividing it equally into thirty-two divisions, representing the points beginning at N at the top, and ending with N at the bottom, (Fig. 4). The amount of deviation on any given course may then be represented by laying off a distance to any convenient scale, equal to the amount of deviation opposite to the point representing the course, and to the right or left as the deviation is E or W.

By laying off a number of these for different courses, and joining the points thus obtained, we shall have a curve of deviations which addresses itself to the eye.

In order to do this in a way which will make a diagram of the greatest service, Mr. Napier, of Glasgow, suggested

NAPIERS CURVE Fig.6



what is known as Napier's diagram, in which the ordinates, on which the deviations are laid off, are not at right angles to the central line, but at angles of 60° in each direction, making a series of isosceles triangles, and converting the diagram into a simple addition and subtraction table.

The central line is divided into degrees and serves as a scale by which the deviations are laid off.

To use it, observe the deviation on any course, and lay off the amount of that deviation on the line passing through the course, on the plain line if the course is correct magnetic, on the dotted line if it be the disturbed compass.

If this course is not exactly on a point lay off the deviation on a line parallel to that passing through the nearest point as A. Having plotted in this way all the observed deviations, a curve is to be traced through them with a free hand, and the deviations on courses not observed upon are given by the intersection of this curve with the dotted or plain lines corresponding to each point.

The examination of a collection of curves, made from actual observations, as in the report of the Liverpool Compass Committee, &c., will show that there is so much regularity that these interpolated deviations may generally be relied upon, although certain cases, such as the U. S.S. Roanoke (Report of National Academy of Sciences for 1863) the irregularities are considerable.

There are two principal practical applications of this diagram.

I. From a given course by compass, which has been steered, to lay down the direct magnetic course which the ship has made.

Find the compass course on the central line. Move the pencil along the dotted line, passing through this course, or in a direction parallel to the *dotted* line, if there is not one passing through the course, until the curve is reached, then return in a direction parallel to a plain line until the pencil reaches the central line, the point thus reached is the correct magnetic course.

It will be observed that this is merely the addition or subtraction, as the curve is to the right or left of the center line of the deviation on this course, since the three sides of the triangle A, B, C, passed over by the pencil are all equal.

II. From a given correct magnetic course to find the course that must be steered by compass in order that the ship may follow the given course.

Find the correct magnetic course on the central line. Move the pencil in a line parallel to the *plain* lines, until it reaches the curve, and back parallel to the dotted lines to the central line, and the point thus reached is the course which must be steered. This is evidently the converse of the preceding operation, and consists in subtracting the deviation which before was added or *vice versa*.

The following verses are given in the English Admiralty Manual to aid the memory.

I.

"From compass course, magnetic course to gain,
Depart by dotted and return by plain."

II.

"But if you wish to steer a course allotted,
Take plain from chart and keep her head on dotted."

43. Having determined the deviations on the correct magnetic courses, it will be very easy to construct a table giving the course to be steered by compass, in order to shape any desired course. It may have the following form:

STEERING TABLE. BINNACLE COMPASS, &c., &c.

Course to be made.	Course to be steered by compass.
N	N 8° W or N $\frac{3}{4}$ W nearly.
N by E	N $2\frac{1}{2}$° E or N $\frac{1}{4}$ E "
N N E	N 13° E or N by E $\frac{1}{4}$ E "
N E by N	N 23° E or N N E "
N E	N 33° E or N E by N "
N E by E	N 43° E or N E $\frac{1}{4}$ N "
E N E	N 52° E or N E $\frac{1}{2}$ E "
E by N	N 61° E or E N E $\frac{1}{2}$ N "
&c.	&c.
&c.	&c.

44. As a table of deviations is troublesome to use, and as errors may be made in applying the correction indicated by the table, it is convenient to make a corrected compass card to steer by.

This may be done in several ways, first: by determining the deviation by swinging, and interpolating these points not observed on from Napier's curve, and then making a card to be put on top of the regular compass card, so distorted that the deviation will be allowed for by steering the ship by the new card. Thus, if the deviation when heading E true magnetic, is one point to the E, the west point of the new card must be one point to the left of the E point of the old card or over the point E by N, and so on all around so that the divisions of the card will not be equal, 11°¼ to a point, but will be greater or less as the deviation is greater or less in each position. If on N courses there is no deviation the N points of the old and new cards will coincide.

Instead of covering up the old card with the new one, the new points may be marked in red ink on the margin of the card outside of the regular division. (See Towson's Practical Information for Figure, page 29).

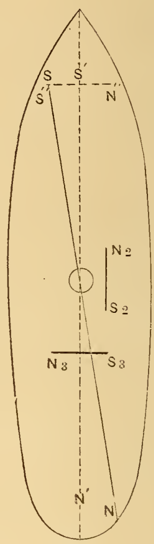
In the form of deviation card, devised by Com. Rodgers, U. S. N., the proper magnetic points are drawn on the outside of the compass, and with the arrow heads indicating them pointing towards the center to distinguish them from the old points.

45. A method of plotting the action of the ship on the needle from values of $\mathfrak{A}$, $\mathfrak{B}$, $\mathfrak{C}$, $\mathfrak{D}$, $\mathfrak{E}$, and $\mathfrak{F}$, too elaborate to be inserted here, is given in the Admiralty Compass Manual, under the head of Dygogram, Nos. 1 and 2.

These drawings give the means of studying the action of the various coefficients, and No. 2 may be used as a steering card.

46. It is possible to correct mechanically the compass of an iron vessel in such a manner that the deviations on all courses may be very much reduced, or even destroyed altogether.

Neglecting for the present, the vertical component (25), the action of the ship on the needle may be represented by that of a large magnet N S Fig. 7, or still further resolved into the action of two magnets $S'N'$, and $S''N''$ at right angles to each other, one in the midship line, the other athwart-ship. The action of the first may be corrected by a small magnet N^2S^2, placed fore and aft., and near to the compass with poles opposite to those of $N'S'$ and the action of the second by a small magnet N^3S^3 athwartship with poles also opposite to those of $S''N''$. In practice this is done by placing the vessel head N, and laying the magnet N^3S^3 upon the deck, either forward or aft. of the compass, turning it end for end or moving it backwards or forwards until the needle points N when $S''N''$ is corrected. Then heading the vessel to the E or W, the magnet N^2S^2 is placed by trial in such a position that it makes the needle point N when $N''S''$ is corrected.



Fig·7

The magnets are then secured by letting them into the deck and nailing pieces of sheet copper over them.

If the magnetic axis of the vessel coincides with its midship line, no athwart ship magnet N^3S^3 will be required, and it is evident also that if the direction of NS is known only, one magnet N^4S^4, *parallel to it* need be used, but as in practical work this is rarely known the two magnets are used.*

The semi-circular deviation due to the permanent magnetism is thus disposed of, and the quadrantal (30) must be corrected by soft iron placed in a position to counteract the action of the soft iron of the ship. This may be done by having two small boxes, called chain boxes fixed one on each side of the compass, to starboard and port, into which soft iron chain, or pieces of annealed wire or iron are put in sufficient quantity by trial to make the compass point to the N cor-

* This method of correction by permanent magnets is known as Airy's method, it having been proposed by the Astronomer Royal of England.

rectly, when the ship's head is N E. S E. S W. or N W., the correction by the magnets having previously been made. The Liverpool Compass Committee use soft cast iron cylinders with hemispherical ends for the same purpose instead of chain, fixing them to port and starboard of the compass, and moving them farther or nearer to produce the desired effect.

This soft iron thus applied corrects D. E which is due to soft iron unsymmetrically distributed, may be corrected by moving the soft iron either backwards or forwards, but it is usually very small and may be neglected. The magnets used for compensating should be of good steel, made very hard and well magnetized sometime (some months if possible) before being used, so as to acquire a permanent condition of magnetism. They may be from fourteen inches to two feet in length and about $\frac{1}{4}$ in. by $1\frac{1}{2}$ in. cross section.

It frequently happens that one correction will interfere with one already made, and it is therefore necessary to repeat the adjustments, with the head in different positions, so as to eliminate the errors, or if any obstinacy remain, they must be averaged on the different courses, and noted in the deviation-table or on the card.

In other words, the compasses may not be *perfectly* corrected, but the deviations will be much reduced, and may be allowed for or not according to the judgment of the officer.

The heeling error may be compensated by a vertical magnet (36).

Experiments, for instruction and practice, on the action of the iron in a vessel and the method of correction may be readily made on shore or on board ship in a harbor, by arranging a table capable of being rotated around a centre, to represent the ship, and placing upon it permanent magnets and pieces of soft iron in different positions, to represent the iron of the vessel, a pocket-compass or a small prismatic compass being used as the ship's compass. For instance, in Fig. 7, N S may be a steel wire or rod magnetized and fastened to the table, the compass placed on the middle of this, supported on a couple of books, will show the semicircular deviation as the table is turned into various azimuths.

This may be then corrected by the use of two small steel magnets $N^2 S^2$ and $N^3 S^3$ placed by trial in the proper positions.

The soft iron may be represented by pieces of iron rod a few inches long and a quarter of an inch in diameter, which have been heated to a bright red and allowed to cool with the fire or cooled in sand slowly. These may be fixed vertically, horizontally, or inclined, and their action in different azimuths noted.

All the phenomena which occur on iron vessels may thus be studied with great ease, and the practice serves to familiarize the officer with the effects which he will meet in practice, and enable him frequently to refer them to the proper cause.

47. The relative advantages of corrected and uncorrected compasses, the latter to be used with a deviation card, table or diagram, have been frequently discussed.

In the English navy, the compasses being usually uncorrected while in the English merchant service, Airy's Method is generally employed. Nearly all the iron blockade-runners captured during the rebellion, had permanent magnets, which were generally torn up by the captains before capture, with a view to make the navigation difficult to the captors.

Most of the iron and many of the wooden steamers of the United States navy have their compasses mechanically corrected.

It has been urged that the permanent magnets may lose their force, and thus introduce an error, which being unexpected might be serious, but as Mr. Towson remarks, no instance has yet been reported in which the magnets lost their charge more rapidly than the ship lost its magnetism. The heeling error, which can hardly be allowed for in practice by the use of a table, and which is sometimes very large, is much reduced by the compensation, and the effects of rolling on the needle are also much diminished.

As the deviation due to the permanent magnetism depends upon the relation between that and the earth's force, in an uncompensated compass it will change with change of magnetic latitude, and a table must be made for new positions.

Altogether the evidence seems to be strongly in favor of compensation, and in fact some of the recently-built English war-vessels have been obliged to come to it, owing to their very large deviations.

The vigilance of the commander must not, however, be relaxed because the compasses are supposed to be corrected, but every opportunity should be embraced to determine whether they have undergone any change.

It is no doubt very desirable to have an uncompensated compass fixed in the best part of the ship (49) to refer to from time to time. If the position selected is one which cannot be constantly occupied by this compass, it may be so arranged that it can at any time be replaced accurately in position by means of marks on the deck.

48. In order that a compass may be good, the needle should be very hard and well magnetized so as to retain its power, the cap should be of ruby or agate, carefully hollowed so as to be even and smooth, and the point should be hard, fine and sharp.

No dirt or dust should be permitted to get into the cap, as it will make the needle sluggish, and enable the point to grind into the cap. The point should be examined from time to time and kept sharp. It is important also that the point should be exactly in the intersection of the two diameters passing through the gimbals, and that it should be exactly at the same height as the centres of the gimbals, a matter frequently neglected by the maker. It has been shown that a compass is more steady, and that the quadrantal correction is more perfect when the card has two parallel needles, the ends of which intersect the circumference of the card at points 60° apart. The Admiralty compass has four needles.

If the bowl is of copper, or better if a stout copper ring surrounds the card, the vibrations of the needle will be calmed, that is their amplitude will be reduced, while the time of vibration will remain the same, owing to an action being set up which appears to be due to currents generated by the relative motion of the needle and the copper. It may be suggested that no means of *cutting off* the action of the ship's iron from the compass can be effectual, since anything which will do that will also cut off the action of the earth's magnetism also, and render the compass useless.

Owing to the peculiar difficulties experienced in finding proper positions for standard compasses on the Monitors, and to the necessity for having the steering compass in or over the steering turret and, therefore, in a position to be affected by the iron of the turret and of the large guns, particularly troublesome because they change their positions with reference to the other iron of the ship when they turn, several methods have been suggested by which the compass could be raised far enough above the turret to be free from the action of the ship and still to be available for the purpose of steering.

Ritchie's Monitor Compass, the first one suggested for this purpose consists essentially of a needle which works in a copper globe supported at a height of six or seven feet above the turret. This needle is attached to and turns with a delicate vertical axis which is long enough to go down through the top of the steering turret, and which carries on its lower end the compass card, so that when the needle above turns in obedience to the earth's magnetic force the card below turns with it and can be consulted by the steersman. In order to prevent friction on its bearing, and strains on the rod, the whole floats in a liquid the specific gravity of which is the same as that of the rod and its floats and card.

A description of its details which are very ingenious will be found in report of Nat. Acad. of Sciences for 1863.

Mr. Schott, of the Coast Survey, has suggested a compass with the under side of the card divided, like a tell-tale compass placed in a copper globe or box above the turret, and read by means of a mirror placed underneath it, with the aid of a glass if necessary, thus dispensing with the vertical axis and simplifying the apparatus.

Report Nat. Acad. Sc., 1863.

Mr. Hilgard, of the Coast Survey, has devised a Magic Lantern Compass, in which the needle raised as before carries a transparent card of glass or mica, an image of which, by a proper arrangement of lenses, is thrown upon a table in the dark steering turret in front of the steersman. The light comes from the sky in daytime, and from a lamp at night. In this form a very short needle with its accompanying advantages, may be used.

49. The ship's standard compass, which should be an azimuth compass, should be placed in a selected position in the midship line where the deviations are the smallest and most regular. In wooden steamers, although there may be large deviations at the steering compass, it will usually be possible to find some place where the needle is not disturbed, but in iron vessels this can hardly ever be the case.

It is, perhaps, desirable that the standard compass should not be mechanically compensated, and if it is not, a table and curve of deviation must be prepared for it and every opportunity taken to verify it when the magnetic latitude is much changed. If upon calculating the coefficients (38) for the standard compass a large + D is observed, it may be reduced by placing the compass over a hatchway or a sky light, where the transverse deck beams being divided will act as two pieces of soft iron athwart ships, and thus partially correct the quadrantal deviation.

50. The magnetic condition of parts of a ship can be determined by bringing a small needle near to the part to be examined. If the N end of the needle is attracted, the part is said to have S polarity, and vice versa.

It will be found in examining iron ships, that they have almost, without exception, N polarity at one end and S at the other, and that the line dividing the different kinds, or the line of no polarity, runs obliquely from the bilge to the rail on either side, or that the surface of no deviation coincides more or less closely with a plane passing through the vessel obliquely. Observations on polarity are important, as indicating in many cases the action which the vessel may be expected to have upon the compass.

51. The instruments required for investigations in the ship's magnetism are, 1. A good azimuth compass. 2. The ordinary ship's compass. 3. Boat compasses, which are very convenient for moving about. 4. The ordinary prismatic compass (Schmalkelder's). 5. A small pocket-compass for testing polarity (50). 6. A needle delicately suspended for vibration experiments. (The prismatic compass, if a fine one, will do for this purpose.) 7. A needle balanced so as to hang in the dip, very delicately hung on points or in jewelled holes for vertical vibration experiments. 8. Two or three small magnets, a small level, and a clinometer of some kind, to determine the angle of keel.

52. The most important books and articles on the subject of the magnetism of iron vessels are as follows:

"Admiralty Manual, for ascertaining and applying the deviation of the compass caused by the iron in a ship by F. J. Evans and Archibald Smith, London: Potter, 1863. 4s. 6d. 8vo, pp. 166, plates."

"First and Second Reports of Liverpool Compass Committee. London, 1857. Small folio, pp. 74, plates."

"Third Report of Liverpool Compass Committee. London, 1862. Small fol., pp. 131, plates; 8 shillings."

"Practical Information on the Deviations of the Compass for the use of Masters and Mates of Iron Ships. By Thomas Towson, Esq. London: Potter, 1863. 8vo, pp. 122; 3 shillings."

"Paper by Edw. J. Johnson, Commander R. N., on Magnetic Experiments on an Iron Vessel, in Philosophical Trans. Part II., 1836."

"Papers by Geo. B. Airy, Astr. Royal in Phil. Trans. 1839. p. 167–213, 1856. Part I., p. 53–99. Athanaseum Ap., 1865."

"Paper by Mr. Evans, R. N., in Phil. Trans. 1860. Part II., p. 337–378, and in Jour. Royal United Service Inst. Vol. IX., pp. 22."

"Papers by Evans and Smith, Phil., Trans., 1861, Pt. I, p. 161–181. Phil. Trans. 1865, Pt. I, p. 263–323."

"Report of Compass Committee in Report of Nat. Acad. of Sciences to Congress for 1863."

The principal investigators in this especial subject have been Capt. Flinders, 1801–1803, Dr. Scoresby, 1819, and later, Major Gen. Sabine, Royal Artillery, Dr. Young, Mr. Barlow, Mr. Poisson, Mr. Airy, Comd. Evans, Mr. Archibald Smith, Capt. Johnson, Mr. Randell, Mr. Towson.

In France it does not appear to have attracted the attention of scientific men to any great extent, and in this country owing to the small number of iron vessels built before the war, it is only within the last few years that it has begun to receive the attention which its importance demands.

It is just now advanced to that point where every officer commanding, or on board of an iron vessel, may add his share to perfecting the general knowledge of the subject, by well devised and carefully executed experiments and observations.

GUNS AND ARMOR.

From "The Engineer."

The trial of the 38-ton gun, subsequent to its being chambered, is probably the last of the remarkable series of experiments on the power of very heavy guns against armor which has been recently carried out in this country and in Italy. We can hardly let the occasion pass without making a few remarks as to the lessons to be learnt from these experiments. The Spezia trials had for their object not only the proof of the gun's powers, but also the investigation of the kind of material and disposition of plates best suited to resist the fire of artillery. The proof of the gun was conclusive. The penetration, as calculated, agreed very well with that obtained, allowing for the velocity left still in the shot after passing through the target. The target's powers, however, to many may constitute the more interesting element in the trial.

Great fault has been found with this part of the programme. Our readers may remember that there were four targets, each consisting of an upper and lower portion, so that we may speak of them as eight targets. All had an inner skin of 1½ inch of iron, and all had 29½ inches of wood. As to front plates, two had solid Schneider steel plates 22 inches thick, two had similar plates made by Cammell and Marrel, of wrought iron. The remaining four were "sandwich" targets. The 22 inches of plate were adhered to in each case, but in two wrought iron was used, divided into 12 inch plates in front and 10 inch plates behind one layer of wood. In the other two, chilled iron 14 inches thick was employed behind 8 inch plates in front, in one case a layer of wood being between. Our Royal Engineers find great fault with the trial, because they maintain that the half-targets, being only 4 feet 4 inches wide, the plates were broken across by the hole made by the shot of a 17 inch gun. This was the case, as they maintain, even when the shot struck the center, but they point out that the conditions were generally still more unfair on the plate, for the shot often struck near the edge, when a corner would be wedged off and detached much more easily than fair penetration would be effected.

Thus, they urge, the trials were spoilt to such an extent that it is difficult to know what importance to attach to them. We have put the objection perhaps more strongly than it may generally be urged, but it is better to do so in order to see the full force of it; and we are bound to admit that the plates did break across, and did detach themselves, and that, if the plate yielded by breaking or splitting so often, it is clear that the shot found less resistance than in fair penetration. Still we think the Italians may fall back on the fact that their object was to test the plates they meant to put on their own ships. We believe these plates represented the actual dimensions to be used, and if so, the object of the authorities was answered. They did not seek to establish the abstract question of the penetration of a shot into 22 inches of iron of unlimited area, but to acquire information as to how their own plates would stand against the gun. Failure by breaking was as fatal and as necessary to investigate as if the shot penetrated. In fact, they followed the sound practical plan of approaching service conditions as far as possible. We believe, then, that in the main the experiment was well carried out. Nevertheless, the objection made by our Royal Engineers is good to a certain extent. The 22 inch plates, it may be urged, not only were the size intended for the Duilio, but also could only have been made broader by shortening them, so that there is not much to object to in them, but with the thinner plates the question is different. They might have been made wider, and would be made wider, or ought to be so, on their vessels. The reason why our own Government have decided on having two layers of plates on our own Inflexible is because we thereby get a complete plate from top to bottom of our turret, instead of a jointed or divided one. No one would advocate the use of 10 inch and 12 inch plates rather than a 22 inch plate of the same width. In this particular, then, we think a mistake was made. Chilled cast iron cannot be said to have been tried in the way advocated in this country, or on the Continent, as far as we are aware, at Spezia, because no one, not even Herr Grüson, advocates using the same thickness of cast iron as of wrought iron or steel.

Herr Grüson urges that a certain mass of it acts like an anvil to hammer in absorbing the blow delivered, by transmitting it throughout its mass, and he appears to have obtained some remarkable results. He would probably not expect much from 14-inch of chilled cast iron. Nor, as a general principle, would he advocate the use of wrought iron in front, for he values the hard surface as suited to throw off the point which the wrought iron surface rather clings to, and even turns in to itself under certain circumstances, when it might have glanced off a harder material. Commander Grenfell, who put forward the advantages he expected to accompany the use of chilled iron in large masses, at the Institution of Naval Architects last week, scouted the application of it in the Spezia targets. The Italian authorities may have had in view the comparative trial of its powers under these particular conditions; but we hardly think that much came of it. One thing seems clear: by the breaking up of their plates the Italian authorities appear to have been guided in the conclusion to which we hear they have now arrived, which is to make thick steel plates with rather thin wrought iron in front. The wrought-iron surface is probably not the most desirable one, but an outside layer of wrought iron of a fair thickness, and rolled in one single unjointed plate might be expected to hold any broken pieces of steel plate beneath it in their position instead of allowing them to detach themselves. It is easy to see that a turret protected by a perforated plate of wrought iron covering thick steel plates, however much split, is in a very different condition from one from which the plates are wholly or partly detached, reducing it to a condition of ruin, confusion, and exposure.

Chilled shot may be and generally are split longitudinally in their passage through thick iron armor, but they go on capitally as long as the pieces are held in their relative positions. Steel plates might act fairly, as proposed, especially on a turret where the arched form of section might assist them. We should think care ought to be taken that the outside covering of wrought iron was bolted by a certain number of bolts that were not in immediate contact with the steel which transmits the blow throughout its mass, and breaks and injures them much more than wrought iron. On this principle then we should have an outside covering of wrought iron to act as a binder. It ought to be thoroughly soft and tenacious, and have as few joints as possible. Inside we should have steel which would transmit the blow through its mass, and would be liable to be split, but its fragments would not become detached. We should be curious to see structures of this kind severely tested. In fact, we cannot doubt that the Italian experiments have added a great deal to our knowledge of the behaviour of armor, and may bring out very good designs, though it is premature to offer a decided opinion yet.

Our Shoeburyness trials are less interesting. Their scope has been much narrower, because we have not made any such extraordinary special series as the Italians. The novelty in our case has been chiefly the magnitude of the scale on which we have now made guns and armor. One or two new principles, however, have been brought out. The 80-ton gun has done well, decidedly better than could have been expected. It has already penetrated 26½ inches of iron, but the specially important feature brought out in our experiments, is the advantage gained by enlarging the powder chamber. We have gained 200 feet per second in velocity in the case of the 38-ton gun under decidedly unfavorable circumstances, and more is to be expected. The abolition of studs by the base-cup rifling system, which has been adopted and proved so successful in the Elswick guns, must sooner or later come in with us; in fact we are making experiments on the subject now. This ought to give a great advantage to the shot. As mentioned above, our projectiles split longitudinally during penetration. This may be in part due to the studholes and studs. We should also hope some experiments may be tried by our Government with the sharp ogival point of $1\frac{3}{4}$ calibres, which is used everywhere abroad, and has been adopted at Elswick. Lastly, as connected with our recent ex periments, we have to notice the terrible effect of common shell on thin armor. A 10 inch Palliser projectile would probably penetrate 12 inches of iron well, but its common shell will penetrate 5 inches of unbacked iron easily, and would produce fearful effects on all behind it, bursting just after it got through, if we may judge from the results of the last experiments. This looks ominous for the Shannon class of partially armored ships, and increases the difficulties to be overcome by our naval architects. In the present state of guns and armor everything is uncertain, and each experiment is likely to reveal some new feature.

BEAMS OF UNIFORM STRENGTH.

By DE VOLSON WOOD, C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE so-called "Unsolved Problems," referred to in Professor Robinson's article in the March number of this Magazine, have now been solved in one way or another. In an article published by the writer in the *Journal of the Franklin Institute*, 1862, vol. 43, page 109, will be found the several problems pertaining to beams fixed at one end, the other end being free, in which the weight of the beam constituted a part of the load. But the difficulty of finding the complete integral of some of the expressions was the same as in Professor Robinson's article. Afterwards, however, I discovered how some of them might be integrated (see *Jour. Frank. Inst.*, 1864, vol. 47, p. 28), and I will apply this method to one of the cases which the Professor rejected as non-integrable by ordinary methods, although I doubt if it will add anything to our knowledge in regard to the form of the beam. The curves represented by the equations can be classified only as *transcendental.*

The solution given by Professor Robinson, of the problem pertaining to beams supported at their ends, the beams forming a part of the load, is the only one I have seen.

The other problems referred to (*Wood's Resistance of Materials*, p. 197), have been solved by means of the *Principles of the Elasticity of Solids*, formulas for the results of which are given in the *Scientific American*, Oct. 22, 1875 (see also *Grashof's Festigkeitslehre*, Berlin, 1866); but the original intention was to have them solved in accordance with the principles of *Ultimate Strength.* We are not, however, informed of any solution by the latter method. One of the general values given by Professor Robinson is:

$$x=\sqrt{\frac{12}{R}}\int\frac{2bydy}{\sqrt{\left(\frac{3P^2}{R}+wby^2+\frac{2}{3}\delta b^2y^3\right)}};$$

in which b is the breadth of the beam, and is constant, δ the weight of a unit of volume of the beam, w the weight per unit of length of the uniform load, P the weight at the free end, R the modulus of rupture, x horizontal, and y vertical.

Let $w=0$, and we have:

$$x=\sqrt{\frac{2\delta}{R}}\int\frac{ydy}{\sqrt{\left(\frac{9P^2}{2\delta b^2R}+y^3\right)}}$$

which was supposed to be non-integrable. Let

$$y=\left(\frac{9P^2}{2\delta b^2P}\right)^{\frac{1}{3}}(z^2-1);$$

then

$$dy=2\left(\frac{9P^2}{2\delta b^2R}\right)^{\frac{1}{3}}zdz$$

and the equation becomes

$$x=\left(\frac{6PR}{b\delta^2}\right)^{\frac{1}{3}}\int\frac{(z^2-1)\,dz}{\sqrt{[3-3z^2+z^4]}}.$$

This comes under a general formula, given in Legendre's *Elliptique Fonctions*, which is written as follows:

$$X=\int\frac{(f+gy^2)dy}{\sqrt{[a^2+2aby^2\cos.\theta+b^2y^4]}}$$

$$=\frac{fb+ga}{b\sqrt{ab}}\,F(c,\theta)-\frac{2ga}{b\sqrt{ab}}\,E(c,\theta).$$

Hence our equation becomes

$$x=\left(\frac{6PR}{b\delta^2}\right)^{\frac{1}{3}}$$

$$\left\{\frac{\sqrt{3}-1}{\sqrt[4]{3}}F(c,\theta)-2\sqrt[4]{3}E(c,\theta)\right\}$$

In this equation $c=\frac{1}{2}\sqrt{2+\sqrt{3}}$.

[Since I wrote the above, I have attempted to verify Legendre's integral, and find that there is something erroneous in it, so that I am not certain that the expression can be integrated even by Elliptic Functions. I trust that his *result* will be found to be correct.]

REPORTS OF ENGINEERING SOCIETIES.

The American Society of Civil Engineers—Ninth Annual Convention.—At 10 o'clock A. M. of Tuesday, April 24, the Convention opened at the Chamber of Commerce, in New Orleans; the opening address being delivered by Col. W. Milnor Roberts, in which he reviewed the history and growth of the Society, and spoke in eulogistic terms of the great engineering work in progress at the mouth of the Mississippi. Prof. Forshey, of New Orleans, well known as the hydraulic engineer, was elected Chairman of the Convention. Eighty-five members, associates and guests were found to be in attendance. The first paper read and discussed was that of Charles Macdonald, C. E., on the Ashtabula bridge. It was generally agreed that the building and inspection of the bridge were grossly defective. A paper on the same subject was read by Mr. E. S. Philbrick, of Boston. The remedy proposed was official inspection by men entirely separate from corporate interest, either appointed by the general or State Government, and a recommendation that a committee of four from the Society be appointed to draft a law, and that individual members interest themselves in procuring its passage in the various States, so as to secure practical uniformity in its workings.

At the afternoon session, a paper on the relative quantity of material in girders of different types was read by Mr. Charles Emery, of New York, and discussed at considerable length. Papers were also presented by Major Howell, on the Improvement of Galveston Harbor; and by the Secretary, for Gen. J. G. Ellis, on the Flow of Water in Rivers. Mr. E. L, Corthell, engineer in charge of construction of the Eads jetties, made some valuable remarks on the progress and problems of that work. He acknowledged that they had been over-confident, and had made some mistakes, but said that the results thus far had been most encouraging, and ensured final success. The chief point discussed was the determination of the slope of the surface of the Mississippi from Carrollton to the Gulf. Mr. W. H. Searles, of New York, read a statement, giving the results of recent delicate test levels upon the line of the Erie Canal, showing more accurate work than had been accomplished by engineers in foreign countries. A paper by Mr. S. Toster Flagg, of Meadville, Pa., upon the insufficiency of steam vacuum pumps, was read by the author, and discussed by Mr. C. E. Emery, and by Mr. W. E. Worthen, of New York.

At the evening session a paper from the late Col. G. W. R. Bayley, on the levees and the river, a criticism on a criticism made by Gen. Warren on a paper of Mr. Bayley, was read.

A report of a committee on the metric system of weights and measures, recommending the adoption of the system was read by Mr. Clemens Herschel, of Boston, Mass., the chairman of the committee. Mr. Philbrick, of Boston, presented a resolution recommending a committee of five to be appointed to confer with other bodies on that subject. A paper by Col. W. M. Roberts, on the American Society of Civil Engineers and its Future, was also read and received with marked approbation by the members of the Convention. Mr. James B. Francis, of Massachusetts, was then called to the chair by Prof. Forshey, who delivered a eulogy on the late Col. G. W. R. Bailey, which was accepted and spread on the minutes of the proceedings.

At the Wednesday morning session, Gen. W. Sooy Smith, chairman of the committee to whom, at the last annual meeting, was referred the question of tests of iron and steel, made a lengthy report, whereupon, on motion, a committee of three was appointed to draft resolutions expressing the thanks of the Convention for the able report, and to suggest a proper method to bring the subject before Congress. The committee reported following resolutions, which were unanimously adopted;

Whereas, In 1872 a committee was appointed of members of the American Society of Civil Engineers, to take into account and to ascertain the best way of establishing a Board for the testing of such metals and alloys thereof, as form parts of such structures and machines as are required for the use of this country; and,

Whereas, In pursuance of such appointment the committee proceeded in their labors so far as to obtain favorable action from the Congress of the United States, not only in a law authorizing the creation of a Board for the purpose of making such tests, but also appropriated money to be expended by said Board in the purchase of the necessary machinery, and in the making of such tests; and, WHEREAS, At a late session of Congress a law was passed by which said Board would cease to exist on the expenditure of the money then appropriated; Now, therefore,

Be it Resolved, That this Society deem the tests proposed to be made of National importance; they, therefore, ask that so much of the sundry civil appropriation bill passed by the Congress, as provides that the Board to test iron, steel, and other metals, shall be discontinued when the money appropriated for its use by the same shall have been expended, be repealed, and the unexpended balance in the hands of the Board shall be re-appropriated, and such further appropriations be made for the use of the Board as it may require to complete the investigation it has undertaken, the sum required for the coming year being $40,000.

Resolved, That every member of this Society be urged to use such influence as they may possess, to obtain favorable and immediate action by the Congress of the United States, in furtherance of the object here prayed for.

Resolved, That the above resolutions be printed, and that each member of this Society be furnished with several copies thereof, to be used in furtherance of the object sought, and that reports of their action in the premises shall be sent by the member to the Secretary, giving the names of such members of Congress as have been seen or addressed on the subject.

JOHN GRIFFIN,
G. BOUSCAREN,
EDWARD S. PHILBRICK,
Committee.

At the evening session Prof. Forshey read a paper recommending certain radical changes in our patent laws, and describing some inventions of his own—especially an irresistible brake, automatic switch, and "express snatch." Col. Hardee presented and read a paper giving his experience in a hurried survey of the railroad from Jackson, Miss., to Jackson, Tenn., in which the lines were run at the rate of nearly thirty-three miles per day. Mr. Bouscaren explained the manner in which the Cincinnati Southern Railroad bridge over the Kentucky River was tested, and giving the vibrations in the bridge and piers, with a blackboard explanation. A resolution of thanks was tendered to all who had extended courtesies to the society, also to the presiding officer, and at 9:30 P. M. the Convention adjourned *sine die*.—*Chicago Railway Review*.

LIVERPOOL POLYTECHNIC SOCIETY.—At a meeting of this society held at the Royal Institution, Mr. C. H. Beloe, C.E., read a paper on "Engineering in America." The disgraceful state of the street paving and the objectionable mode of construction adopted in the street tramways were referred to. A description was given, and a drawing exhibited of the New York Elevated Railroad, which traverses the streets at the height of the first floor of the houses, being supported on columns placed near the curbstones. After mentioning the great works which were undertaken for the removal of the reef at Hell Gate, the author described the suspension bridge in course of construction over the East River to connect New York with Brooklyn. Mr. Beloe then described the principal features of the Centennial Exhibition at Philadelphia, and alluded to the most interesting of the engineering exhibits. In speaking of the waterworks of Philadelphia, it was mentioned that the average consumption of water in twenty of the principal American cities amounts to no less than sixty gallons per head per day, as much as ninety gallons being the average in one place. In conclusion, the author expressed his astonishment at the progress which has been made in America in the manufacture of iron and steel, and of machinery, and his conviction that the export of these articles from England is already a thing of the past.

IRON AND STEEL NOTES.

SOLID CAST STEEL.—The difficulty encountered in obtaining properly solid cast steel in masses is well understood. The means of overcoming the difficulty have probably yet to be found. Sir J. Whitworth's compressed steel represents one attempt. The system of compression tried some years ago at Neuberg in Styria is another. Yet a third system is now proposed by M. Pourcel, the manager of the steel works at Terrenoire. At the November meeting of the Société de l' Industrie Minerale, a paper was read on the manufacture of steel perfectly free from air cells by M. Pourcel, which involves some very important propositions. M. Pourcel began by saying that from the day that the different phases of the Bessemer process were fully explained, the means of casting steel free from cells was a *a priori* discovered:

"It was well known that silicon prevents the formation of carbonic oxide; here then the principle was established, what remained then was to draw from it all its important consequences, and apply them, and it is from calculations and experiments based on the above law, that the authorities at Terrenoire had been enabled to solve the problem, and achieve their present great success in casting steel free from air cells.

"In decarbonizing a gray silicious pig iron in the Martin furnace by means of wrought iron or steel scrap, we find on taking samples after each addition of steel or iron, that at a given moment the cast metal is riddled with air cells. If, on the other hand, we submit to analysis the homogeneous samples—*eprouvette non soufflee*—taken immediately before the honeycombed sample—*eprouvette soufflee*—we find silicon in the homogeneous sample, whilst the honeycombed metal may contain particles of interposed cinder, but no free silicon.

"Such is the analytical result; the effects may be produced synthetically. By adding silicon in the form of silicide of iron to a bath of steel already formed, we completely eliminate the air cells. This steel is, however, generally red-short, and this red-shortness has been, and is still attributed, not only by steel manufacturers, but also by the majority of our most distinguished chemists, to the presence of silicon. This explanation we admitted in the first instance reservedly, but now we cannot help thinking that it is open to doubt. Our own opinion is that silicon in the proportions usually found in steel in nowise affects its quality, making it neither red nor cold-short.

"The air cells existing in cast-steel are due—as Bessemer himself demonstrated some eight or ten years ago—to the oxide of carbon formed in the liquid steel by an intermolecular re-action between the carbon of the metal and the oxide of iron formed during the act of casting. When the metal remains liquid sufficiently long, the gas escapes, but generally speaking, the temperature at which steel is cast being only a little higher than that at which it solidifies, the carbonic oxide remains imprisoned, and gives rise to air cells, disposed symmetrically and perpendicularly round the great axis of the ingot.

"Silicon prevents the formation of these air cells—because it has a greater affinity for oxygen than carbon has—and this, of course, by intermolecular combustion, the oxidising body being either peroxide of iron or carbonic acid, or both, but then instead of being gaseous, the product of the oxidation is a solid body formed in the metal itself, and is disposed uniformly between its molecules. It is the silicate of iron, the cinder interposed between the molecules, that renders the metal red-short and diminishes its quality as cast metal.

"To get rid of this cinder we must add to it a base which will render it sufficiently fusible to allow of its separating by liquation. For this purpose we use manganese; and here lies the chief point. Manganese is employed in the Bessemer process to free the cast metal from the peroxide of iron which it holds in solution, it reduces it to its lowest step of oxidation by taking up the equivalent of its oxygen, and the oxide of manganese thus formed, combining with the silicate of iron, renders the cinder extremely fluid and it separates by liquation.

"MM. Troost and Hautefeuille, in their valuable works communicated to the 'Académie des Sciences,' have confirmed this explanation of the part played by the manganese added at the end of the Bessemer process, a theory published by Valton eight years ago in a memoir communicated to the 'Bulletin de l'Industrie Minerale.' Now this theory has entered into practice, and its results have been most fruitful.

"Acting on this law, we have substituted for a silicide of iron a 'double silicate of iron and manganese' for adding to a bath of steel for the purpose of producing metal free from air cells. The two reducing elements, silicon and manganese, act simultaneously on the mass in a state of fusion, reducing the peroxide of iron and preventing the formation of carbonic oxide; and the result of their oxidation is a silicate of protoxide of iron and protoxide of manganese, a body which is very fluid at the temperature at which steel solidifies, and which separates easily by liquation. As to the silicide of iron in excess, we are convinced that its effects are not injurious.

"We cannot here enter into an examination of the experiments on which this theory is based without departing too far from the subject before us, but at one of the next meetings this question will be laid before the members by a person more authorized to speak on the matter. The principle of this manufacture, which we have now discussed, is very simple in theory, but its application is a delicate and more complicated matter. However, we may say that the practical difficulties have in a great measure been surmounted, and at present we are producing at Terrenoire cast steel of nearly every shade characterising forged steel, from the hardest to the softest.

"The perfect homogeneity of these cast steels, resulting from their chemical composition, and the perfect equilibrium of their molecules produced by a process of annealing or tempering of varying nature, will, we firmly believe, lead to results never before attained in the production of forged steels. This is, however, a new subject with which we personally are not so well acquainted, and which M. Euverte, the director of the Terrenoire works, intends submitting for discussion at the next monthly meeting of the society."—*Engineering.*

RAILWAY NOTES.

The *Gazette de Lausanne* gives the following statistics respecting the working of the railway system of Switzerland during 1875, and which, if not quite recent, contains some useful information. It appears that the total length of the Swiss network at the close of last year was 1454 kilos. (901½ English miles), of which 214 kilos. was double line (132¾ miles). The average gradient of these lines is 6.83 per thousand (1 in 1610). The mean radius of the curves is 1718 meters (about 86 chains). The capital expended upon these lines is estimated at 515,033,048 f. (£20,701,322), which averages 362,511 f. per kilo. or £23,335 per mile. The rolliug stock consisted of 340 locomotives, 154 tenders, 1037 passenger carriages, capable of containing 46,663 persons; 214 luggage vans, and 5571 good trucks of the capacity of 55,583 tons. With this *materiel* 15,455,157 passengers were carried in the above-mentioned year, 2½ per cent. of which were 1st class, $21\frac{1}{10}$ per cent. 2nd class, and $76\frac{4}{10}$ per cent. 3rd class, besides 3,992,665 tons of goods. The total expense of working these lines amounted to 26,328,313 f. and the receipts to 48,887,658 f., giving a net profit of 22,559,345 f., which represents a dividend of 4.23 per cent. on the capital employed. During the same year 124 persons were wounded and 59 killed by accident. The staff is composed of 6430 employés and 4322 workmen.

Fast Trains *vs.* Safe Trains.—We observe that some of our English neighbors have become alarmed by several severe accidents on very fast passenger trains—notably those of the Great Western road, which average fifty-one miles an hour (excluding stops), and on some stretches make sixty miles an hour—and are raising the question whether such speed is safe or profitable. It is announced that since the last great accident to the "Flying Dutchman" train on the great Western it has been decided to reduce the speed of that train, "over what may be considered the more dangerous part of the road," to forty miles per hour. The Bristol *Times* is so wrought up by the frightful accident referred to that it suggests governmental interference to prevent such great speed—a hint of another form of railroad restriction which our grangers do not seem to have thought of. It quotes approvingly from another writer :

"Why do we (says he) cage in the top of the monument, and fence round the cog wheels of a machine, and require the use of the Davy lamp in mines, if we admit the right of the traveling public, in a preposterous fancy for fast going, to expose themselves and others to the risk of such casualties as that which occurred recently. There is no material known which the tremendous rate of these railroad racers must not severely try, and the cursory tap of the hammer upon the wheels, as they pause for a few minutes at long intervals on their course, are more a seeming than a substantial security. . . . We are quite sure that shareholders would be glad that government took the matter in hand, for they have no difficulty in understanding that the wear and tear of these flying trains upon permanent way, upon locomotives, and upon rolling stock, are such as must greatly interfere with profits. Indeed, it is calculated that a general moderation of speed to forty miles an hour would be attended with an advantage more than equivalent to the abolition of the passenger duty."

Quoting this, *Herapath's Journal* adds :

"An accident such as that to the Flying Dutchman may excuse and justify the interference of government. Safety is of far more importance to travelers than speed, and as railways are the only means of communication between distant points the public have a right to be assured of the greatest safety in traveling, at least that every precaution shall be taken to prevent accidents."

Possibly our British friends will not consider it impertinent for us to suggest, with all respect to the magnificently solid character of British road-beds, superstructure and engines, that with the more strongly built cars, the anti-telescoping platforms, the self-loosening couplers and the automatic air or steam brakes in use on first-class American railroads, such accidents as the one referred to would be almost impossible of occurrence.—*Railway Age.*

ENGINEERING STRUCTURES.

The South Pass Improvement.—A correspondent of the New Orleans *Times*, under the date of April 29th, writes as follows:

In 1875, the board of civil and military engineers, which reported on the improvement of the mouth of the Mississippi, said: "It is 11,900 feet from the 30 feet curve inside the Pass across the bar to 30 feet outside. The minimum depth on the bar is seven feet." Captain Eads began his work June 14, 1875, less than two years ago, and he now has a 30 foot channel and more through nearly the whole line of the 12,000 feet of jetty channel. There remains just at the lips of the jetties a short shoal with 21½ feet of water on it, where two years ago there were but 7½ feet. This is the only remnant of the old bar left, and it is so short a distance from the deep water inside to the deep water outside, that a large steamship drawing 23 feet might lodge on the ridge of this bar, and both her stem and stern would be in deep water. It is calculated that the spring or June rise will scour out this small obstruction, and leave a channel of full 24 feet, and once gone, it is now certain that it will not return.

No man with scientific knowledge or practical common sense can examine the jetties and doubt this. With high water, there will be at ebb-tide a solid prism of water with an average of 20 feet thick and 800 wide pouring through these jetties and over the bar at a velocity of six to seven miles an hour. It throws a solid volume of water many miles out into the gulf, and no deposit is possible at the mouth of the jetties.

The jetties are protected from the sea by miles of sand bars which have formed behind the jetties along the whole line, and the channel is now like a canal 1000 feet wide cut through sand bars and walled up.

The fears as to the filling or silting up that were entertained and freely expressed in the most influential quarters, during the early history of the Suez Canal is an event that may now be considered extremely unlikely. Last year between the two seas only 52,700 cubic meters of "stuff" were removed, and the canal was navigated with facility by steamers drawing as much as twenty-seven feet, and over 400 feet in length. The bed of salt which forms the bottom of the Bitter Lakes, is gradually dissolving, so that this portion of the canal is being gradually but steadily improved, and with the increase of vegetation along the banks of the canal there is a prospect of the production, in a not distant future, of a fertile and populous tract of country out of a sandy waste.

The report by the engineer of the Tay Bridge undertaking states that the whole of the eighty-five piers are placed in position. Seventy of these are completed, having the permanent girders placed thereon, with cross girders and timber platform laid for about 2375 feet, and 3074 feet of hand-railing erected. Of the remainder, five piers are completed to the full height of the string course, and the girders of the spans laid thereon. Two large caissons are sunk to the requisite depth; one is one-third filled with concrete, the other is made ready to be filled. One of the twenty-one feet caissons is thoroughly filled with piles, and ready to receive the concrete foundation; and the last of the twenty-one feet caissons is placed in position in the bed of the river. Neither on the night of the accident during the gale, nor at any other time when even severer gales prevailed than on that night, has the slightest damage accrued to any part of the bridge placed in a permanent position.

ORDNANCE AND NAVAL.

The Bessemer.—This vessel has lately undergone considerable alteration. The swinging cabin has been taken out, and the low ends fore and aft built up level with the upper deck. The extra internal capacity thus gained has been appropriated at one end to a second class cabin, and at the other to the accommodation of the officers, crew, &c. The original steering gear has been taken out and Brotherhood's new gear put in in its place. A trial took place off Great Grimsby lately, when it was found that with 130 tons of coal on board the vessel made about fifteen knots an hour. As, however, she was only worked up to twenty-five pounds pressure of steam, doubtless a greater speed will yet be obtained. The new steering gear was found to be rather too powerful, but this Mr. Brotherhood explained could be easily remedied. The ship, however, answered her helm readily Though not much sea, there was a very considerable swell on, so that the steadiness of the Bessemer was severely tested. She did not, however, roll to any great extent, probably owing to the large bilge keels—two feet six inches in depth—with which she is fitted.

The Thetis.—Her Majesty's ship Thetis has undergone some peril, and met with an accident of an unusual character. In the navy machinery catastrophes of all kinds abound, and it is to the credit of the ship that she should have given the world something new in this direction. It appears that the Thetis, running home from Port Said in a tolerably crowded marine highway, succeeded in partially getting rid of her screw propeller—that is to say, it came off the shaft and stuck in the screw aperture instead of going straight to the bottom. In the language of rowing men, it became a passenger. This feat accomplished, the Thetis next proceeded to perform one of still more startling dimensions. She so effectually hid herself, that for twenty-five days no one could find her, and as she had started with six days' provisions only, it is clear that during the latter portion of her voyage nothing very eatable was left on board. A whole host of questions rise up at this point and demand answers. Why did the screw come off the shaft? How did the ship conceal herself for twenty-five days in a comparatively populous sea? Why did not the Thetis make for some port under sail? Many more questions might be asked, but we venture to think that if those we have put are repeated in the House of Commons, some good may be done. At all events, we may learn something as to the utility of "masts and spars" in her Majesty's navy and in a breeze.

BOOK NOTICES.

Proceedings of the Institution of Civil Engineers.

The Sewage Question. By C. Norman Bazalgette.

Abstracts of Papers in Foreign Transactions and Periodicals. Edited by James Forrest, Secy. London: Printed by Wm Clowes and Sons.

In treating the Sewage Question the Author deals with the various systems that have been tried within the past few years, classifying them for the purpose of his discussion as follows:

1. Treatment with Chemicals.
2. Application of Sewage to Land, including irrigation and intermittent downward filtration.
3. Dry Earth System.
4. The Liernier or Pneumatic System.
5. Seaboard and Tidal Outfalls.

The paper and discussion cover nearly 200 pages.

We shall publish most of the essay in an early number of this magazine.

The abstracts are as usual papers of much value to the engineering profession.

A Treatise on the Science and Practice of the Manufacture and Distribution of Coal Gas. New York: D. Van Nostrand. Issued in Parts at 40 cts. each. (4 now ready.)

This treatise commences with a short sketch of the history of gas lighting, gives a full account of the geology, lithology and chemistry of the raw material—coal, and afterwards follows the gas, step by step, from the retort to the burner, showing what is done and what is required at every stage of the manufacture and distribution of coal gas. After this naturally follows a brief account of the manufacture of gas from materials other than coal, and some description of the inventions designed to supersede coal gas by the carburation of atmospheric air, and the gases produced by the decomposition of water. Finally, some space will be devoted to an account of the utilization of residuals. In this way it is intended to give a full and complete account of the science and art brought down to the most recent times.

The treatise is published in monthly numbers, royal 4to, and printed in clear, bold type, and each part illustrated with numerous engravings and plans. Its preparation has been confided to careful and experienced editors, and no pains nor expense will be spared to render it complete in every department.

The general plan of the work will be seen from the following divisions:—

Part I, Chap. 1. History of Gas Lighting. Chap. 2. Coal—Geology of Coal; Origin and Formation of Coal; Various Kinds of Coal; Analysis of Coal; Gas Producing Power of Coal; Storage of Coal; Heating power of Coal.

Part II, Chap. 1. Manufacture of Gas. Chap. 2. Retort Houses; Retorts, Iron and Clay; Hydraulic Main. Chap. 3. Condensers and Exhausters. Chap. 4. Scrubbers and Washers. Chap. 5. Purifiers.

Part III, Chap. 1. Chemistry of the Manufacture and Purification of Gas. Chap. 2. Photometry.

Part IV, Chap. 1. Storage. Chap. 2. Station Meters. Chap. 3. Gas Holder Tanks—Brick, Iron, Stone, Concrete, Composite. Chap. 4. Gas Holders. Chap. 5. Pressure Registers. Chap. 6. Designs and Plans for Gas Works.

Part V, Chap. 1. Distribution. Chap. 2. Station Governors. Chap. 3. Mains. Chap. 4. Services. Chap. 5. Valves. Chap. 6. District Governors. Chap. 7. Meters.

Part VI, Chap. 1. Consumption. Chap. 2. Fittings, Burners, Regulators, etc. Chap. 3. Public Lighting.

Part VII, Treatment of Residual Products; The Various Processes of Manufacturing Gas from other Material than Coal, etc., etc.

Strength and Calculations of Dimensions of Iron and Steel Constructions. Translated from the German of J. J. Weyrauch, Ph. D. New York city: D. Van Nostrand. Price $1.00.

Another translation of this same work has already been briefly noticed in these columns; and we expressed the view that the contents of the volume were not in such practical form as would adapt it to the uses of the working engineer. The present translation seems to us much less open to that objection, and certainly it contains an immense amount of useful data, entirely outside the formulæ, besides examples tending materially to elucidate the latter. The book is rendered much more practical; and its whole arrangement is, to our minds, better and well calculated to render its various topics more accessible to the student. As regards the intrinsic merits of Professor Weyrauch's work, and in our previous strictures on the other translation, we intended no disparaging reflection upon them; they are undoubtedly great, and the volume should be carefully studied by all engineers. It is based on a general view of the results obtained in the extended course of experiments made in Europe and in this country to determine the properties of iron and steel. As these trials have shown the somewhat startling fact that (to quote Professor Weyrauch) "the method hitherto employed in calculating the dimensions of iron and steel constructions have been entirely wrong," it is hardly necessary to point out the importance of any work which deduces a formula which gives all "the requisites for a simple and rational determination of dimensions."—*Scientific American.*

The Elements of Analytical Mechanics. By De Volson Wood, A.M., C.E. New York: John Wiley & Sons. 1876

[From "Engineering and Mining Journal."]

The science of mechanics has a twofold importance. Its practical importance consists in this: that the principles and processes of all mathematical physics are derived from it. It is of the greatest utility in the explanation of the phenomena of the world external to us, and it is indispensable in a thousand applications of science to the needs of life. But its importance in a theoretical point of view is perhaps still more striking. The development of every physical science has been characterized by certain inevitable and successive processes. First of all comes the collection of facts; then the formation of a theory to explain them; then the establishment and verification of this theory by the successful prediction of the future; and, finally, the reduction of the science to its simplest principles and most general form. Through all these processes the science of mechanics has passed, and it has finally attained to a perfection and completeness to which no other physical science can make pretension. It is, therefore, not only the foundation-science to the principle of which every special branch of physics conforms; it is the *type*-science: and the degree of completeness of any physical science is to be determined by the conformity which it exhibits with the principles of mechanics, and the advance which it has made in the process of development which the type-science seems to have well-nigh completed.

Corresponding to this twofold aspect of the science, we have two methods of considering it in its relations to scientific education. First, it may be taught merely with reference to its practical uses. It is not to be denied that in certain applications of the science, as in engineering, this method is quite sufficient, and it is not necessary, for these practical purposes, to consider the theory of mechanics in all its generality. Secondly, it may be studied in its most general form; as it is developed, for instance, in the writings of the great master Lagrange, to whom, perhaps, more than to any other it owes its perfection. This method, however, while it is of incalculable value and importance to any student who wishes to acquire broad scientific views, is lacking in a practical point of view, and in its original form is probably too abstract for most beginners. Fortunately a third way is open in the judicious union of the two methods. This, then, is the problem which presents itself to the writer on analytical mechanics for the purposes of instruction. While he is to take care that the practical character of the science shall be clearly brought out, so that the student shall not find himself provided with tools which he is unable to use, he is also to see to it that the scientific spirit, the perfection and generality of the great type-science are kept distinctly in view. There are indications that Professor Wood has proposed this problem to himself in the book which we review. We cannot, however, compliment him upon his success in its solution.

The most essential requisites of any treatise on mechanics, whether it is practical or theoretical in character, are clearness and accuracy. We will, therefore, proceed first to examine the book with reference to these points. On the very first page we find the following remarkable definition, "Matter is that which receives and transmits force." In point of fact, we have no reason to believe that force is transmitted by matter. Taking the force of gravitation as an example, we have strong reason for believing that it is not transmitted in time or dissipated in space. In a word, Professor Wood defines matter by a property which it is not known to possess. The absurdity of the definition can be made still more apparent by substituting for the word *force* its definition given on the second page. We then find that *matter is that which receives and transmits that which tends to change its state with regard to rest or motion!*

Perhaps it will be well, at the outset, to indicate what is the matter with Professor Wood. A recent article on the subject of Force, which he has contributed to Van Nostrand's Magazine, reveals the trouble. We do not propose to examine the article in detail. Its errors are too apparent to escape the notice of any one who has a sound elementary knowledge of the subject. We refer to it only on account of the light which it throws on Professor Wood's errors. "I do not think it advisable," says our author, "to consider anything as force or as the measure of force which cannot itself be measured by this unit [the pound]. Momentum MV is measured in *foot-pounds* [!], and hence *generally* is not a measure of force!" In this quotation we have the whole difficulty. Professor Wood, here and throughout his book, has utterly failed to appreciate the distinction between forces and the effects which they produce.

Within recent years a school of philosophers has sprung up, taking its origin in Germany and France, which has assumed to change the nomenclature of the science of mechanics, and to call that force which, in accordance with the system of Newton, should be energy. We do not propose to discuss the advisability of this change. One effect of it is very apparent: it has confounded many popular scientists, and it seems to have hopelessly confused Professor Wood, for he gives us a definition of force according to one system, and a definition of matter according to another. But this is not all. In order that the student may not have "a vague and confused idea" as to the real meaning of the word force, he is to consider but one kind of force, "that which is equivalent to a pressure." Now, according to the generally accepted meaning of the word pressure (and we cannot suppose any other signification is intended, since no definition is given), it denotes the statical effect of a force, not the force itself. Nor can it be considered, in any true sense, to be equivalent to the corresponding dynamical effect, which is motion, since these magnitudes are referred to entirely different units. According to Professor Wood, however, the magnitude of a force is known only when it is given in pounds; yet he does not altogether reject the dynamical measure of force, although he fails to point out what the unit of measure is. Many other passages in the book seem to show that Professor Wood imagines pressure and motion to be equivalent. For instance, on page 67, "We have seen that a pressure, when acting upon a free body, will produce a certain amount of motion, and that this motion is a measure of the pressure"! But motion cannot be the statical effect of force. What, then, can Professor Wood mean by pressure? Is this notion introduced to prevent the student from getting confused ideas?

Professor Wood's inaccuracies are not confined to the subject of force. For instance, we are told that "density is the mass of a unit of volume"!—an example of the author's prevailing carelessness in confounding the thing with its measure. Again, on page 45, we have the remark, "Every moving body on the surface of the earth does work," etc. Here we have moving matter confounded with working force. Again, on page 58, "One of the grandest generalizations of physical science is, *that no force in nature is lost.*" Here we have force again confounded with energy. Again, on page 89, "A statical couple cannot be equilibrated by a single force. It does not produce translation, but simply rotation." Of course a statical couple does not produce motion of any kind. Again, on page 180, we have central forces defined as "such as act directly towards or from a point called a center." The distinguishing characteristic of a central force—that its intensity is a function of the distance—is ignored. According to the above definition, all forces are central. Again, on pages 203 and 220, we have specific reference made to the principle of D'Alembert, yet this principle, historically one of the most important in the science, is not elsewhere mentioned, and is nowhere stated or explained. Again, on page 59, we find the following: "The terms '*Impulsive force*' and '*Instantaneous force*' are frequently used to denote the effect of an 'Impact'; but since the effect is not a force they are ambiguous," etc. We doubt if any writer of reputation ever used the above terms in the sense indicated; but what are we to think when Professor Wood follows the above remark with this statement?—"An *incessant force* may be considered as the *action* of an infinite number of infinitesimal impulses in a finite time"!

We could cite many more evidences of Professor Wood's inaccuracy and want of clearness, but we shall confine ourselves to a very few. In his treatment of the important subject of the moment of inertia we find no attempt at an explanation of the functions of such a quantity. The only relation between the moment of a force and the moment of inertia of a body with reference to an axis is that they are both measures of capacity, although of different kinds. The one measures the capacity of a force to produce rotation about the axis; the other, the capacity of the body to store up work during such a motion. In place of a clear statement of the use of such quantities in the science, Professor Wood gives a fanciful relation which he thinks he has detected between them. The moment of inertia, he says, may be considered as the *moment of a moment*, whatever that may mean. We need scarcely say that such a motion is useless and confusing, and does not exist in any physical sense.

Again, we find an elaborate description of Kater's method of determining the length of the simple second's pendulum, in which most of the space is devoted to a description of a method of determining the time of oscillation. This description might well have been omitted from an elementary text-book, and the space devoted to a clear explanation of the theory of the apparatus employed. No such explanation is given. The construction and use of Kater's pendulum depends upon two principles. First, the axes of oscillation and suspension are convertible. Second, the time of the oscillation is a minimum when the axis of suspension passes through the principal center of gyration. This second principle is of equal importance with the first; but Prof. Wood ignores it altogether, and misses the point of the method.

Referring to the preface of the book, we find the following remarkable paragraph: "This work, though analytical, is, in a certain sense, the reverse of Legendre's celebrated *Mecanique*

Analytique. Legendre, at the outset, deduced a general equation from which all others were derived," etc. This is again explicity stated on page 161, where the equation is actually given with the annexed comment:

$$\text{"}R\,\delta\, r - \Sigma\, m \frac{d^2 s}{dt^2}\,\delta\, s = 0 \qquad (118)$$

This is the most general principle of mechanics, and M. Legendre made it the fundamental principle of his celebrated work on *Mecanique Analytique, which consists chiefly of a discussion of equation* (118) "!

Few of our readers will need to be informed that the *Mecanique Analytique* was not written by Legendre, but by Lagrange. Nor was any such equation discussed in the *Mecanique Analytique*, nor did the author of that masterpiece of analysis propose or attempt to base the science on any single formula. Almost the first words in the book are, "I propose to reduce the theory of that science [mechanics], and the art of resolving the problems which belong to it, to *general formulas.*" Professor Bartlett of West Point, about the year 1850, was the first to show that the "general formulas" of Lagrange could be deduced from the single equation which Professor Wood has coolly accredited to the author of the *Mecanique Analytique*, or rather to M. Legendre, ignoring not only Lagrange's work, but that also which has been done by Professor Bartlett to develop the science in this country.

But let us return to the preface, and ascertain in what certain sense Professor Wood's book is the reverse of "M. Legendre's celebrated work on *Mecanique Analytique.*" "This work" (his own), continues Professor Wood, "at first establishes the equation for motion due to a single force, and by adding principle after principle the most general equations become established. The latter method is the one by which every science is at first developed, and presents great advantages over the former in the course of instruction; but the former, as a method of pure analysis, cannot be excelled." With respect to all this, we have to say: First, the method by which the science of mechanics has been developed is not the best method to be pursued in a course of instruction, because the principal importance of its study is as an exercise of the intellect, since it is a perfect illustration of the nature of scientific reasoning; and in this respect its *logical* development is of the utmost importance. Secondly, the science has not been developed in the way indicated by Professor Wood, as a very cursory examination of its history will show.

It is not necessary to extend these instances of gross carelessness and inaccuracy further; indeed we should not have devoted this space and prominence to a review of the work were it not that Professor Wood has the reputation, and deservedly has it, of being a very able mathematician ; he should appreciate the fact that a widely known name and a high reputation impose corresponding obligations. The errors and lack of precision which abound in this work might be passed over as excusable in the work of an unknown beginner, but they become quite unpardonable when they are the result of gross carelessness, we might almost say slovenliness, in a master like Professor Wood, who undoubtedly knows better. We understand that this work has been adopted as the text-book in a number of our colleges and schools, still another reason for impressing upon its author the necessity of revising it thoroughly and correcting it before a second edition is allowed to appear.

The prevailing inaccuracy of our scientific education is, we believe, largely due to the fact that the country is flooded with text-books in which the prevailing characteristics are careless and reckless statements. We want no more of them, and certainly expect none from so high an authority and experienced a mathematician as Professor Wood. R.

MISCELLANEOUS.

PHOSPHOR copper used in the preparation of phosphor bronze is prepared, according to Dr. H. Schwarz, as follows: A crucible is fettled with a mixture of bone ash, silicic acid, and carbon, granulated copper is laid in and covered with a quantity of the fettling mixture, and the whole is fastened down with a cemented cover. Soda and glass can be added to promote fusion. At a fusing heat, the silicic acid acts on the phosphate, the phosphoric acid is reduced and taken up as freed by the copper. On the occasion of an experiment, fourteen parts silicic acid were added to eighteen bone ash, and four powdered charcoal, four parts soda and four powdered glass, made up with a little gum water, for lining the crucible; the latter was closed, the copper put in, covered with the mtxture and melted at a red heat. The lining mixture was but little incinerated. The copper grains appeared grey red, well run, and entirely free from blister. On analysis the copper gave 0.5 to 0.51 per cent. phosphorus. Another experiment gave copper with 3.25 per cent. phosphorus.

M. BERT, of Milan, has for a long time been conducting a series of experiments with a view of determining what are the physio-logical effects of condensed air on the human system. Many engineering works of the day involve the necessity of workmen carrying on their operations under various pressures of air, to say nothing of the fact that the rise and fall of the barometer involve us all in changes differing only in degree from that which the diver experiences when he descends from the surface of the water to a depth of fifteen or twenty fathoms beneath it. M. Bert thinks that the influences of ordinary changes of air as indicated by the barometer are due exclusively to the varying quantities of oxygen contained in the air inhaled. The pressure of oxygen and the consequent amount of it which finds its way into the blood, he shows, depends upon the centesimal proportion of it in the air and upon the barometrical pressure, and he says that the mischief which operatives in air-tight dresses so often experienced from the density of the air they are compelled to breathe might be completely obviated if an atmosphere were composed of air and nitrogen nicely adjusted in proportion to the pressure under which the mixture was passed along the tubes.